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EVOLUTION OF THE ORBITAL IMPROVEMENT PROGRAM.(U)
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Technical Memorandum

EVOLUTION OF THE ORBITAL IMPROVEMENT PROGRAM

by S. C. DILLON

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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The Orbital Improvement Program (OIP) is a massive computer program that determins and predicts orbits for the Navy Navigation Satellite System (Transit system). The system became operational in 1963 and has played a vital part in providing all-weather navigation to worldwide users. The system has been continuously updated and improved. Today, navigation results are regularly under 10 m for operational satellites, providing accuracy far beyond any expectations of the early 1060's. This report describes the evolution of the program, its operational history, and how it has improved navigation accuracy.

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EVOLUTION OF THE ORBITAL IMPROVEMENT PROGRAM

by S. C. DILLON

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY
Johns Hopkins Road, Laurel, Maryland 20810
Operating under Contract N00024-78-C-5384 with the Department of the Navy

ABSTRACT

The Orbital Improvement Program is a massive computer program that determines and predicts orbits for the Navy Navigation Satellite System (Transit System). The system became operational in 1963 and has played a vital part in providing all-weather navigation to worldwide users. The system has been continuously updated and improved. Today, navigation results are regularly under 10 m for operational satellites, providing accuracy far beyond any expectations in the early 1960's. This report describes the evolution of the program, its operational history, and how it has improved navigation accuracy.

A

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ILLUSTRATIONS

1. INTRODUCTION

The Second-Generation Orbital Improvement Program (OIP-II), in use since 1963, has been continuously improved. OIP-II, written in assembly language, is a massive software complex of 23 core overlays in the IBM 7094. As the second-generation Navy Navigation Satellite System (NNSS) draws to a close, it seems appropriate to trace briefly its operational history.

This paper will show the evolution of OIP, its history, and how it has improved navigation accuracy. Included are charts, graphs, and experiments that depict these improvements. A detailed description of the NNSS is given in Refs. 1 and 2.

Ref. 1. H. D. Black, R. E. Jenkins, and L. L. Pryor, "Planned Improvements in the Transit System (1975)," Navigation, Vol. 22, No. 4, winter 1975-76, pp. 352-360; also published as APL/JHU TG 1305, December 1976.

Ref. 2. R. R. Newton, "The Navy Navigation Satellite System," Space Research, VII, North-Holland Publishing Co., Amsterdam, 1967, pp. 735-763.

2. BACKGROUND

The Navy Navigation Satellite System (NNSS), originally called the Transit System, was conceived in 1958 by F. T. McClure of APL. The underlying concept that led to the development of the system was inspired by the first launch of an artificial satellite into orbit, Russia's Sputnik I, in 1957. W. H. Guier and G. C. Weiffenbach were monitoring the beeps transmitted by the passing satellite and plotting the received signals at precise intervals. They noticed that a characteristic Doppler curve emerged. Since celestial bodies follow fixed orbits, they reasoned that the curve could be used to describe the satellite orbit. Later, they demonstrated that all of the orbital parameters for a passing satellite could be determined by Doppler observation of a single pass from a single fixed location. Dr. McClure concluded inversely that "if the satellite orbit were known, Doppler shift measurement could be used to determine one's position on earth," thereby suggesting a new method for navigation — more precise than any yet known — available anywhere on earth without regard for weather conditons.

The system was developed with the primary objective of providing precision updates for the location of Polaris submarines. Since 1964, at least one satellite has existed to provide continuous updates to the Polaris fleet. The NNSS represents a new concept in celestial navigation that makes use of a man-made "star" to take an active part in the navigation process (Ref. 3).

Using Fig. 1 as a guide, the system will be discussed briefly.

Ref. 3. R. B. Kershner, "The Doppler Concept and the Operational Navy Navigation Satellite System," presented at the International Geodetic Symposium on Satellite Positioning, Las Cruces, NM, 12-14 October 1976.

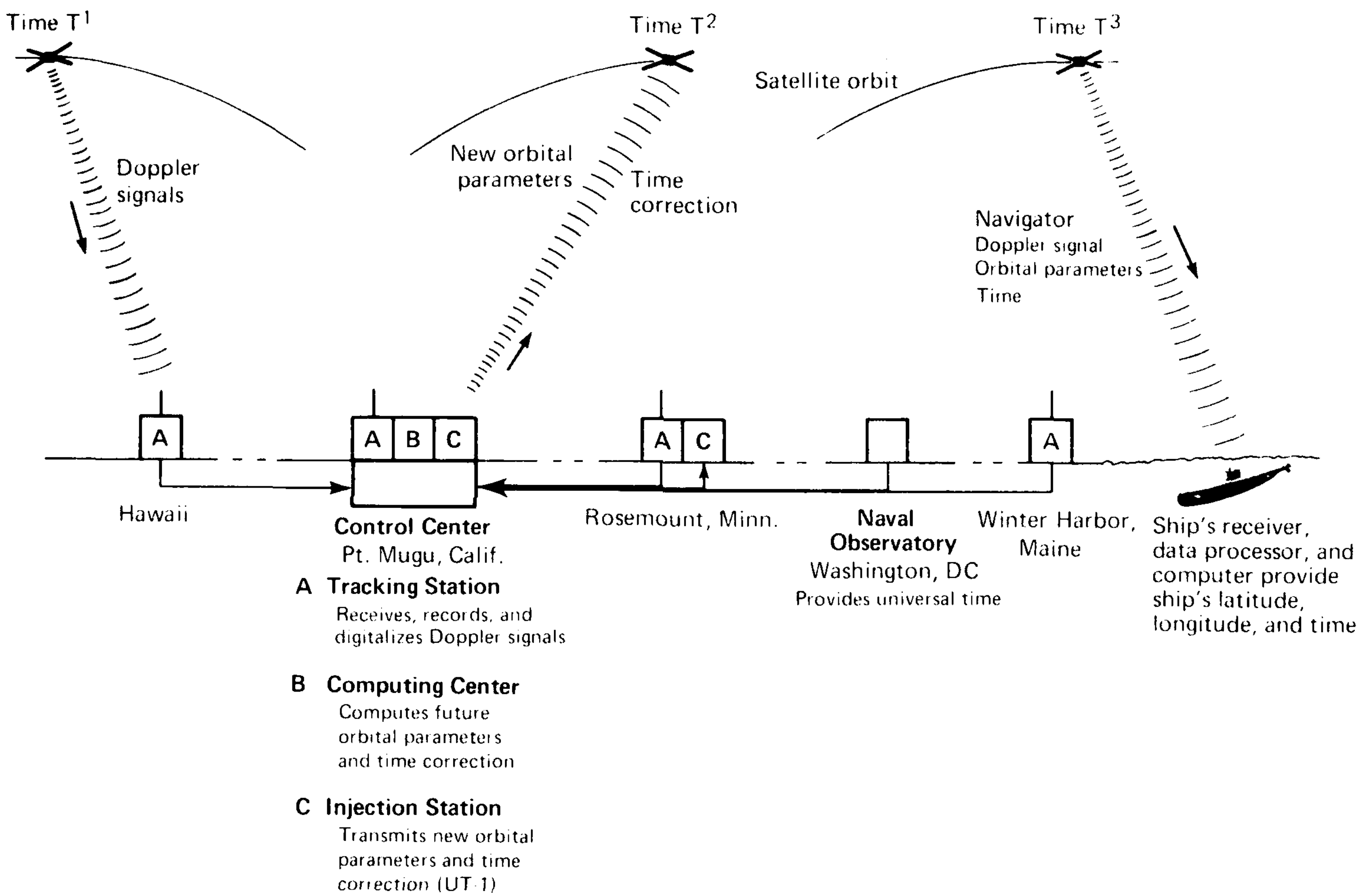


Fig. 1 The Navy Navigation Satellite System.

3. SATELLITES

Navigation satellites are launched into 600 mi circular orbits from Vandenburg Air Force Base in California by a Scout four-stage rocket. Traveling at 240 mi/min, the satellites orbit the earth every 107 min, transmitting a message every 2 min.

Any spot on the earth rotates within range of a single satellite at least twice during a 24-h period; indeed, the system is operable with but a single satellite. The earth revolves beneath the plane of such a satellite about 27° of longitude per orbit, or approximately the distance from Los Angeles to Minneapolis. To provide a more frequent availability, a constellation of five satellites is used. These satellites, criss-crossing at the poles in orbits that are equally separated, provide contact anywhere on earth on almost an hourly basis. Presently the five satellites in service provide near-uniform coverage. The satellites were de signed in 1963 for a lifetime of 5 years. The newest satellite has been in orbit for five years, the oldest for 12 years.

The satellites contain receivers to accept navigation message data for the 16-h memory and transmitters to relay the information to earth. To ensure a valid navigation message, satellite memories are refilled every 12 h. The spacecraft transmit two coherent frequencies, 150 and 400 MHz, so that the navigator can make ionospheric corrections.

4. GROUND NETWORK

The Navy Astronautics Group (NAG) operates the satellite constellation and keeps them supplied with information on a 24-h basis. NAG is a network of operational injection facilities and tracking stations connected to a centralized control center and ground computing complex by high-speed data communication lines.

The tracking stations receive and process Doppler data on each pass of the orbiting satellites. These data are transmitted to a computing center via a high-speed computer-to-computer communications network. The computers receive the Doppler data; the Orbital Improvement Program (OIP) reconstructs the exact orbit of the satellite. On the basis of the reconstructed orbits, OIP constructs or predicts the next 16 h of the satellite orbit. These predictions are reformatted into a satellite injection message and are transmitted to injection stations. At the proper time the injection message, called an "injection," is transmitted to the satellite and stored in the satellite memory. An injection requires precise timing, but only 15 s are required to fill the satellite memory. The injected data are valid for 16 h.

5. NAVIGATION SETS

A user's navigation set is essentially a radio receiver that contains a frequency-cycle counter and a computer. The receiver is tuned to pick up the signals from a passing satellite. The navigator, when he uses the satellite to determine his position, measures the received frequency at prescribed intervals and demodulates the satellite carrier to recover the satellite ephemerides. Using the frequency measurements, the satellite orbit, and his own ship's speed, the navigator can compute his position.

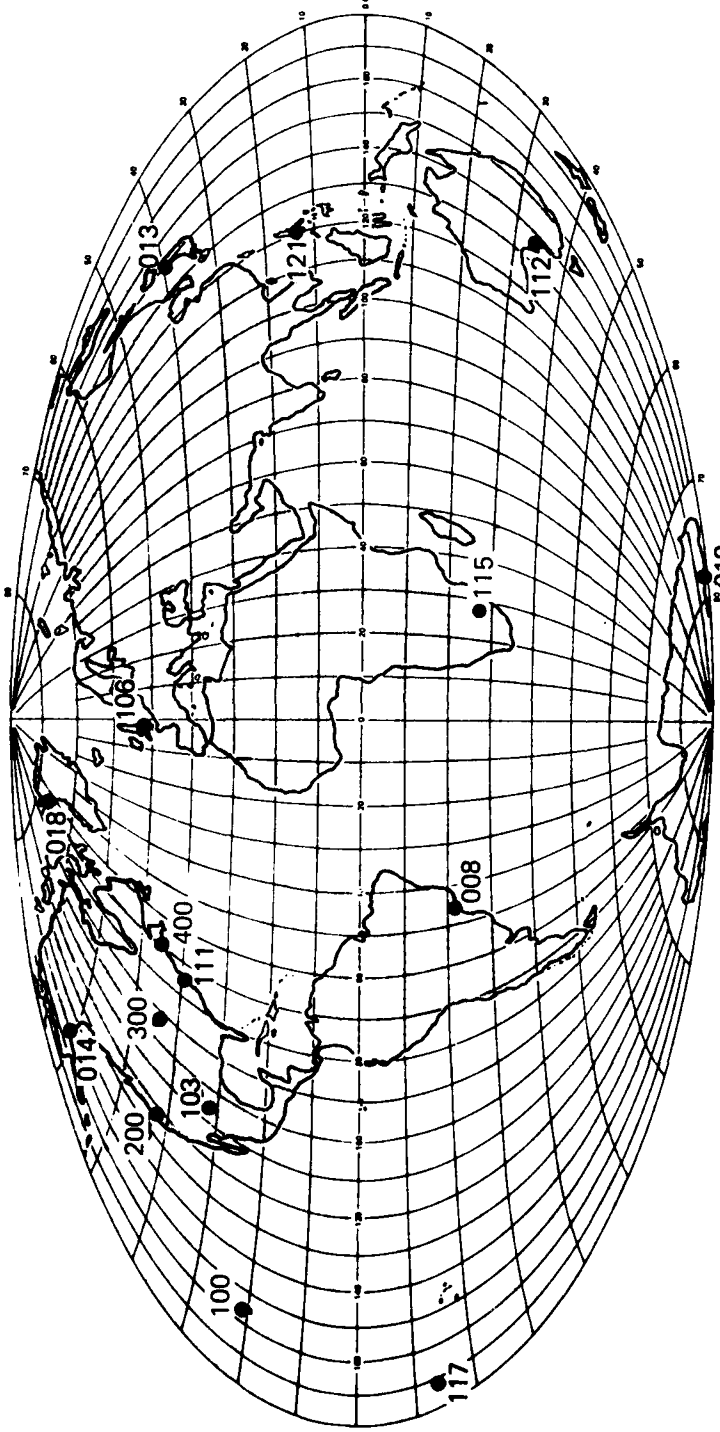
In 1967 the NNSS was made available for commercial use. Today, there are 4000 receiving sets in use, only about 700 of them by the military.

6. HISTORY

To show the sequence of improvements in OIP, a span of data from one satellite was tracked using each of the potential OIP models. One of the early experimental Transit satellites (63041), with data from 1964, was selected since its OIP characteristics are available in all the OIP programs. Despite the fact that the data and the satellite were from the beginning of the Transit program, it was felt that data from an early period would provide a clear demonstration of the improvements that had been achieved in tracking accuracy. Consequently data were collected over a 36-h span, and the satellite orbit was updated over a 30-h span. There were two station networks involved in the study: OPNET, four operational stations located in Maine, Minnesota, California, and Hawaii; and Tranet, a variable number of stations located worldwide. Figure 2 shows the OPNET and the subset of Tranet used. Table 1 gives the orbit of the satellite used in the experiment.

Table I
Orbit of satellite used in experiment.

Satellite	1963 49B
Altitude (nmi)	
Apogee	598
Perigee	582
ε	0048
i (deg)	89.96
Ω	101.4 (Day 173, 1964)
Launch Date	5 December 1963



008 Sao Jose, dos Campos, Brazil
013 Misawa, Japan
014 Anchorage, Alaska
018 Thule, Greenland
019 McMurdo, Antarctica
100 Wahiawa, Hawaii
103 Las Cruces, N. Mex.
106 Lasham, United Kingdom
111 Howard County, Md.
112 Smithfield, Australia
115 Pretoria, South Africa
117 Tafuna, Samoa
121 San Miguel, Philippines
200 Laguna Peak, Calif.
300 Rosemount, Mich.
400 Winter Harbor, Maine

Fig. 2 OPNET and TRANET station sites.

The first OIP SYSMIT, a self-contained operational or near-operational edition of the program, was delivered to NAG in December 1963. This version of OIP used zonals and sectorials through 4-4 (Fig. 3) and set 1.0 station coordinates. With SYSMIT, tracking could be accomplished to 300 m.

The geopotential expansion used in OIP is given by:

$$U = \frac{K}{r} \left\{ 1 + \sum_{n=2}^{\infty} \sum_{m=0}^{\infty} \frac{\Pi_n^m(\sin \varphi)}{r^n} \left[C_n^m \cos m\,(\lambda - \Lambda_G) + S_n^m \sin m\,(\lambda - \Lambda_G) \right] \right\},$$

where

r, φ, λ = the inertial radius, latitude, and longitude of the satellite;

Λ_G = right ascension of Greenwich relative to Aries;

K = gravitational constant times the mass of the earth (= GM);

$$\Pi_n^m(x) = -\sqrt{\frac{(n-m!)}{(n+m!}}\ (1-x^2)^{m/2} \frac{d^m}{dx^m} P_n(x);$$

x = $\sin \varphi$;

C_n^m = $J_n^m \cos m\, \lambda_n^m$;

S_n^m = $J_n^m \sin m\, \lambda_n^m$; and

C_n^m, S_n^m = coefficients of the partially normalized associated Legendre polynomials of degree n and order $m(\Pi_n^m)$.

In OIP the quality of the tracked* ephemerides is judged on how well it fits the Doppler data. Each satellite pass is navigated

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* "Tracked" in this context means that the ephemerides are produced using initial conditions that have been least-squares fit to a set of Doppler data passes. We have uniformly used ephemerides only within this span.

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KLNM

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20	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00									

Fig. 3 Set 1.0 geodesy.

using the full precision, tracked ephemerides; tropospheric refraction is removed using Hopfield's model (Ref. 4). Two-position parameters and a frequency correction are solved when the satellite is at a point closest to the station. The two-position parameters are: ECA(ℓ), the error (relative to some input position) in the direction of the satellite velocity vector, and ECR(ρ), the direction of the station-satellite range vector.

In January 1965, a new version of OIP, Mk 2 Mod 1, was implemented. Zonal and sectorials through 6-6 (Fig. 4) and set 2.0 station coordinates were used. With the implementation of Mk 2, navigation errors were reduced to 92 m. Plot 3 in Appendix A shows the difference in navigation between the geodesy of the set 1.0 and set 2.0 station coordinates. Plots 1 and 2 in Appendix A show the navigation results of the first two versions of OIP.

Before Mk 2 was implemented at NAG, work had begun on the next version of OIP. All the J_n^m and λ_n^m terms were updated to geodesy set 3.0 except the even zonals, which were updated to 1964 King-Hele values (Ref. 5). Mk 3 OIP included zonals and sectorials through 8-8 (Fig. 5) and set 3.0 station coordinates. The tracking error was reduced to 84 m. Plot 5 in Appendix A shows improvements from set 2.0 to set 3.0 geodesy. Plot 4 displays the navigation results of set 3.0 geodesy.

Before set 3.0 geodesy was implemented, analysis revealed that near-resonant conditions existed with geopotential harmonics of order 13 and 14. The oscillation was removed when tracks were made with the resonant terms included. The new geopotential model was called 3.5 (Ref. 6).

The 3.5 geopotential model consisted of all harmonics through degree n = 8, zonals through degree 12, and some sectorials. The model included a few resonant terms of order 13 and 14 (Fig. 6).

Ref. 4. H. S. Hopfield, "Tropospheric Effects on Signals at Very Low Elevation Angles," APL/JHU TG 1291, November 1975.

Ref. 5. D. G. King-Hele, G. E. Cook, and H. M. Watson, "Even Zonal Harmonics in the Earth's Gravitational Potential, Nature, Vol. 202, No. 4936, 6 June 1964, p. 996.

Ref. 6. S. M. Yionoulis, "Determination of Coefficients Associated with the Geopotential Harmonics of Order Thirteen," J. Geophys. Res., Vol. 71, No. 6, March 1966, p. 1768.

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KLAM

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14	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00					
15	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00				
16	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00			
17	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00		
18	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	
19	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
20	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00									

Fig. 4 Set 2.0 geodesy.

```
                    COCRD

KTIME=07/16/62
KK    = .39860150+06   KRF   = .63781660+04
KJMAX= 20
                    KN1  =           5    KM1  =            0    KN2  =           15   KM2  =           15

KJNM
  M=     0           1           2           3           4           5           6           7           8           9  ETC.
 N
  1       0+00        0+00
  2 -.10827-02        0+00  .84277-05
  3  .26760-05  .69464-05  .52220-05  .44211-05
  4  .14000-05  .30304-05  .25865-05  .35912-05  .12027-05
  5  .28000-07  .10127-05  .20243-05  .64730-06  .25952-05  .31399-05
  6 -.37000-06  .51462-06  .11412-05  .27165-05  .30298-05  .27478-05  .11837-05
  7  .59300-06  .86608-06  .25336-05  .24360-05  .74937-06  .10715-05  .48417-05  .92686-06
  8 -.70000-07  .90853-06  .59428-06  .13044-05  .45929-06  .46903-06  .38839-05  .10707-05  .10120-05
  9 -.17700-06        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
 10  .50000-06        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00
 11       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00
 12 -.31000-06        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00
 13       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00
 14       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00
 15       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00
 16       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00        0+00
 17       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
 18       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
 19       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
 20       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00
KLNM
  M=     0           1           2           3           4           5           6           7           8           9  ETC.
 N
  1       0+00        0+00
  2       0+00        0+00 -.23300+00
  3       0+00  .11606+00 -.25412+00  .32568+00
  4       0+00 -.24775+01  .40771+00  .27925-02  .60196+00
  5       0+00 -.88314+00 -.44577+00  .28257+00 -.66305+00 -.32428+00
  6       0+00  .15729+01 -.11866+01  .31540-01 -.52831+00 -.38083+00 -.25150+00
  7       0+00  .63827+00  .64926-01 -.16109+00  .78453+00 -.37315+00  .35203+00 -.14591+00
  8       0+00 -.28255+01 -.18319+00  .60633+00  .66061+00 -.62832-02  .26721+00 -.56025-01  .32097+00
  9       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
 10       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00
 11       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00
 12       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00
 13       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00
 14       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00
 15       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00
 16       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00        0+00
 17       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
 18       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
 19       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
 20       0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00        0+00
          0+00
```

Fig. 5 Set 3.0 geodesy.

```
                       DOCRO

KTIME=07/16/62
KK    = .??86315u+06    KRI   = .63781660+04
KJMAX= 20
                         KN1   =          5   KM1   =            0   KN2   =          15   KM2   =          15

KJNM
  M=      0          1          2          3          4          5          6          7          8          9  ETC.
 N
  1       0+00       0+00
  2 -.10827-02       0+00  .54277-05
  3  .26760-05  .69464-05  .52220-05  .44211-05
  4  .14000-05  .30304-05  .25365-05  .35912-05  .12027-05
  5  .28000-07  .10127-05  .20243-05  .64730-06  .25952-05  .31359-05
  6 -.37000-06  .51462-06  .11412-05  .27165-05  .30298-05  .27473-05  .11437-05
  7  .59300-06  .66008-06  .25336-05  .24360-05  .74937-06  .10715-05  .49417-05  .92596-06
  8 -.70000-07  .90953-06  .53424-06  .13044-05  .45829-06  .46603-06  .38339-05  .10707-05  .10120-05
  9 -.17700-06       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
 10  .50000-06       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00
 11       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00
 12 -.31000-06       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00
 13       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00  .39040-06
 14       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00  .36000-06
 15       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00  .30000-07       0+00
 16       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00       0+00       0+00       0+00
 17       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
 18       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
 19       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
 20       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00
KLNM
  M=      0          1          2          3          4          5          6          7          8          9  ETC.
 N
  1       0+00       0+00
  2       0+00       0+00 -.22300+00
  3       0+00  .11665+00 -.75417+00  .31568+00
  4       0+00 -.24775+01  .63771+00  .77525-01  .50196+00
  5       0+00 -.88314+00 -.46577+00  .25257+00 -.66305+00 -.32428+00
  6       0+00  .15729+01 -.11366+01  .31540-01 -.52331+00 -.38083+00 -.25150+00
  7       0+00  .63927+00  .64026-01 -.16109+00  .78453+00 -.37715+00  .35203+00 -.14591+00
  8       0+00 -.28255+01 -.13219+00  .50633+00  .66061+00 -.62832-02  .26721+00 -.56025-01  .32097+00
  9       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
 10       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00
 11       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00
 12       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00
 13       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00  .18042+00
 14       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00  .26130+00
 15       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00  .34278+00       0+00
 16       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00       0+00       0+00       0+00
 17       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
 18       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
 19       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
 20       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00       0+00
          0+00
```

Fig. 6 Set 3.5 geodesy.

Mk 3.5 OIP used set 3.0 station coordinates. Other improvements included a new earth perturbation force subroutine (Ref. 7), more accurate tropospheric corrections, and a new inject task (Ref. 8).

Another improvement to the 3.5 geopotential model was the addition of the small-force tape. In OIP, the modeled forces acting on the satellite are partitioned into "large" and "small" forces. The small forces are those that are small in magnitude compared to the oblateness term in the earth's gravitational expansion and whose values are relatively insensitive to small changes in the satellite's position. The orbit determination process requires repeated numerical integrations of the satellite's orbit over the same time span. Under operational conditions, changes in the initial orbit between iterations are small; their integrated effect usually changes the position at a given time by no more than 100 m. Variations this small do not cause significant changes in the small-force values. Thus, these forces are not reevaluated on each iteration, but are read from the small-force tape, unless the satellite's position for a given time has changed by more than the predetermined threshold.

In February 1966, the Mk 3 OIP was implemented. In addition to improving tracking results to 77 m, Mk 3 reduced the navigation error in the prediction span by more than 50%. Results obtained by Mk 3.5 are shown in plots 6 and 7 in Appendix A.

Throughout the earlier part of 1966, extensive geodesy runs were made to compute a new geopotential model. In generating 4.5 geodesy, approximately 1000 passes were used to determine some 300 parameters (station coordinates, geopotential coefficients, etc.) (Ref. 9).

Ref. 7. B. B. Holland, J. A. Yingling, and M. A. Walko, "The Second Generation Integration Routine (IGC)," APL/JHU TG 466 (Rev.), 1970.

Ref. 8. H. S. Hopfield, "Two-Quartic Tropospheric Refractivity Profile for Correcting Satellite Data," J. Geophys. Res., Vol. 74, No. 18, August 1969, pp. 4487-4499.

Ref. 9. H. D. Black, "Doppler Tracking of Near-Earth Satellites," APL/JHU TG 1031, August 1968.

As in earlier programs, the first Mk 4 prototype used the Harris-Priester modes of the upper air density (Ref. 10) in computing the ephemerides. This model was found to be inadequate. The rising solar cycle forced us to implement the newer Jacchia air density model in the ephemeris complex (Ref. 11) in the hope that it would diminish the ephemeris error. (The normal operation of Transit requires a prediction of the satellite position 12 to 24 h into the future. Errors in the density model cause period errors in the satellite ephemeris that, if large enough, can be catastrophic.)

An attempt was made to implement the next Mk 4 prototype only to have it fail because of a very severe magnetic storm (May 1967). An intensive investigation (Ref. 12) that followed revealed that the air density model consistently overestimated the density of the air during disturbed magnetic periods. Minor parameter adjustments to the basically sound Jacchia model solved the problem.

After four prototypes, Mk 4 was implemented in June 1968. Navigation errors for tracks were reduced to 24 m with Mk 4 Mod 5. In October 1969, another version, Mk 4 Mod 6 was implemented. The major change included in this version involved the formation of the Doppler shift. It was modified to include both the second-order classical term and the relativistic term (Ref. 13). Results of 4.5 geodesy are shown in plots 8 and 9 in Appendix A. The geopotential coefficients are listed in Fig. 7.

The next version of OIP, Mk 4 Mod 8, was implemented in January 1974. Improvements in this version included the capability to process Tranet continuous-count integrated (CCI) data, along-track force fit (drag fitting), polar motion compensation to account for

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Ref. 10. I. Harris and W. Priester, "Theoretical Models for the Solar-Cycle Variation of the Upper Atmosphere," J. Geophys. Res., Vol. 67, No. 12, November 1962, pp. 4585-4591.

Ref. 11. L. G. Jacchia, "Static Diffusion Models of the Upper Atmosphere with Empirical Temperature Profiles," Smithson. Contrib. Astrophys., Vol. 8, No. 9, 1965, pp. 215-257.

Ref. 12. A. Eisner, "Atmospheric Density Studies," APL/JHU TG 951, December 1967.

Ref. 13. R. E. Jenkins, "A Satellite Observation of the Relativistic Doppler Effect," Astronom. J., Vol. 74, 1969, p. 960.

DOCRD

KTIME=07/16/62
KK = .39860150+06 KRE = .63781660+04 CCD = .30000000+01
KJMAX= 20
KN1 = 5 KM1 = 0 KN2 = 15 KM2 = 15

KJNM

N \ M=	0	1	2	3	4	5	6	7	8	9 ETC.
1	0+00	0+00								
2	-.10827-02	0+00	.87279-05							
3	.26677-05	.76149-05	.41929-05	.57185-05						
4	.13948-05	.29723-05	.27873-05	.41479-05	.14283-05					
5	.42582-07	.14921-05	.25322-05	.14901-05	.12182-05	.37312-05				
6	-.36683-06	.85615-06	.12761-05	.15108-05	.30193-05	.30179-05	.84464-06			
7	.58194-06	.22745-05	.23832-05	.12157-05	.13485-05	.26835-06	.26279-05	.90218-06		
8	-.72357-07	.62333-06	.12532-05	.11901-05	.23330-06	.11122-05	.25308-05	.10449-05	.92667-06	
9	-.16425-06	.10014-05	.13480-05	.20012-05	.11527-05	.23258-06	.13525-05	.51550-06	.63774-06	.88375-06
10	.49859-06	.21515-06	.60064-06	.16572-05	.13462-05	.20465-06	.99716-06	.64665-06	.20242-05	.14952-06
	.42783-06									
11	-.20019-08	.12587-05	.21641-05	.14110-05	.12498-05	.13496-05	.11767-05	.29546-05	.94323-06	.13533-05
	.33160-06	.21582-06								
12	-.31000-06	0+00	0+00	.10714-05	.38476-06	.75452-06	.10418-05	.92730-06	.12206-05	.10122-05
	.49372-06	.80588-06	.13111-06							
13	0+00	0+00	0+00	0+00	.10664-05	.22886-05	.96735-06	.10716-05	.26377-05	.90396-06
	.84083-07	.10539-05	.74447-06	.71072-06						
14	0+00	0+00	0+00	0+00	0+00	.10138-05	.13485-05	.18650-05	.14625-05	.99922-07
	.33607-06	.51190-07	.55437-07	.16353-06	.33536-06					
15	0+00	0+00	0+00	0+00	0+00	0+00	.38632-06	.16312-05	.95777-06	.12256-05
	.66576-06	.68199-06	.39629-06	.41985-06	.10166-06	.12291-06				
16	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	.22240-06	.49007-06	0+00	0+00			
17	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00		
18	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	
19	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
20	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00									

KLNM

N \ M=	0	1	2	3	4	5	6	7	8	9 ETC.
1	0+00	0+00								
2	0+00	0+00	-.24940+00							
3	0+00	.14370+00	-.27566+00	.37624+00						
4	0+00	-.23908+01	.46617+00	-.53339-01	.50465+00					
5	0+00	-.19475+01	-.22911+00	-.91215+00	-.51956+00	-.28115+00				
6	0+00	.27318+01	-.10909+01	-.38596-01	-.43869+00	-.43153+00	-.21297+00			
7	0+00	.69275+00	-.96276-01	-.28117+00	-.63407+00	-.61664+00	.40896+00	.39340-01		
8	0+00	-.81157+00	-.11693+00	-.90924+00	-.73558+00	.53132+00	.30070+00	.12727+00	.31201+00	
9	0+00	-.12801+01	.96416+00	-.35348+00	-.74377+00	-.44058+00	.27202+00	.38961+00	-.16069+00	.29493+00
10	0+00	.11897+01	.11814+01	-.27796+00	.75535+00	-.32080+00	-.37778+00	.11139+00	-.18678+00	-.13205+00
	.23851-01									
11	0+00	.10202+01	-.51230+00	-.10308+01	.12237-01	.57126+00	-.64781-01	-.28086+00	.23938+00	.16656+00
	.23610+00	-.86134-01								
12	0+00	0+00	0+00	.10268+01	-.31691+00	.59088+00	-.17071+00	-.22790+00	.22587+00	.55750-02
	-.47136-01	-.18306+00	-.41265-01							
13	0+00	0+00	0+00	0+00	.47847+00	.18514+00	-.51663+00	.16110+00	-.96926-01	-.34656+00
	.91882-01	-.18731+00	.17963+00	.16439+00						
14	0+00	0+00	0+00	0+00	0+00	-.93059-01	.51688+00	-.73523-01	.70552-01	.62457-02
	-.63929-01	.21597+00	-.20047+00	-.14044-01	-.20119+00					
15	0+00	0+00	0+00	0+00	0+00	0+00	.37410+00	-.27436+00	.26843+00	-.10056+00
	.65600-01	-.16412+00	-.25878+00	-.19654+00	-.13117+00	-.14621+00				
16	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	.53106-01	-.16297+00	0+00	0+00			
17	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00		
18	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	
19	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
20	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00	0+00
	0+00									

Fig. 7 Set 4.5 geodesy.

the fact that the spin axis of the earth is not aligned with the geographical north-south pole (Ref. 14) and the transformation of ephemeris to navigator space. Transformation to this space is accomplished by rotating the satellite position to earth fixed space using the correct spin axis location and performing the inverse rotation, this time about the geographic pole. The last rotation is exactly the inverse of the navigator's operation. Hence, the true earth-fixed satellite position will result when the ephemeris received from the satellite is used. The geopotential model for this version remained the same, but new (polar motion corrected) station coordinates were included for the operational stations. These coordinates were constrained to net zero longitude displacement in the coordinate reference system so that no discontinuity accrues to the fixed-site surveyor, see plots 10 and 11 in Appendix A.

Throughout 1974, major changes were made to OIP, and several prototypes were compiled to check them out. Some of the changes were: the inclusion of the body-tide perturbations on the satellite; and the use of an improved model of the radiation pressure force, of drag fitting, and of editor looping (an orbital determination technique whereby corrections to the input orbit are obtained via an analysis of the pass navigation parameters.

The GM (gravitational constant times the earth mass) was updated from the value of 398601.5 ±0.6 km^3/s^2 to a more accurate determination, including the atmosphere, of 398600.8 ±0.4 km^3/s^2. The speed of light remains at 299 792.5 km/s.

A different algorithm for computing the gravitational forces acting on the satellite at each integrator step was also implemented. The algorithm reduces the computing time by almost 50% (Ref. 15). The 4.5 geopotential model was replaced with the larger WGS-72 model

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Ref. 14. V. L. Pisacane, B. B. Holland, and H. D. Black, "Polar Motion Compensation in the Navy Navigation Satellite System," Developments in Science and Technology, APL/JHU DST-1, 1973, pp. 14-16.

Ref. 15. V. L. Pisacane, B. B. Holland, and H. D. Black, "Recent (1973) Improvements in the Navy Navigation System," Navigation, Vol. 20, No. 3, Fall 1973, pp. 224-229.

which has more than twice the number of coefficients (477 versus 226). Polar motion coordinates were replaced with NWL-10D-01 (Refs. 16, 17, and 18), but once again altered to preserve the longitude reference of the system (Ref. 19). Navigation results, now under 20 m with the Mk 5 Mod 2 OIP from the experimental satellite, are shown in plots 12 and 13 in Appendix A.

In December 1975, the Mk 5 Mod 2 version of OIP was implemented. For the first time, twice-a-day updates* became a thing of the past. Navigation results, regularly under 10 m with operational satellites, improved beyond any expectation we had in the early 1960's. Mk 5 Mod 2 will probably be the last OIP to be used before the IBM 7094 computer is replaced.

The tracking results for all the geopotential models can be found in Table 2. Appendix B gives a brief outline of the different versions of OIP that have been used to improve the system.

A more realistic view of OIP accuracy improvements is shown in Fig. 8. The chart gives the actual tracking error for each geopotential model for the satellites in operation during that period. The navigation error that is experienced with present operational

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* Updates here refer to the daily operational OIP runs. At least once every day OIP uses the latest Doppler observations reported by the OPNET tracking network to reconstruct the present orbit; from this, OIP extrapolates predicted orbital positions that the satellite will traverse from minute to minute while broadcasting the new data.

Ref. 16. B. B. Holland, A. Eisner, S. M. Yionoulis, and H. D. Black, "Implementation of WGS-72 Geopotential Set in the Navy Navigation Satellite System," Developments in Science and Technology, APL/JHU DST-4, 1976, pp. 15-17.

Ref. 17. T. O. Seppelin, "The Department of Defense World Geodetic System 1972," Can. Surv., Vol. 28, No. 5, Ottawa, Canada, December 1974, pp. 496-586.

Ref. 18. B. B. Holland, A. Eisner, and S. M. Yionoulis, "The Effect of WGS-72 Geopotential in the Navy Navigation Satellite System on Station Surveys," APL/JHU TG 1311, August 1977.

Ref. 19. S. C. Dillon, G. Gebel, and L. L. Pryor, "Navigation at the Prime Meridian Revisited," Navigation, Vol. 24, No. 3, 1977, pp. 264-266.

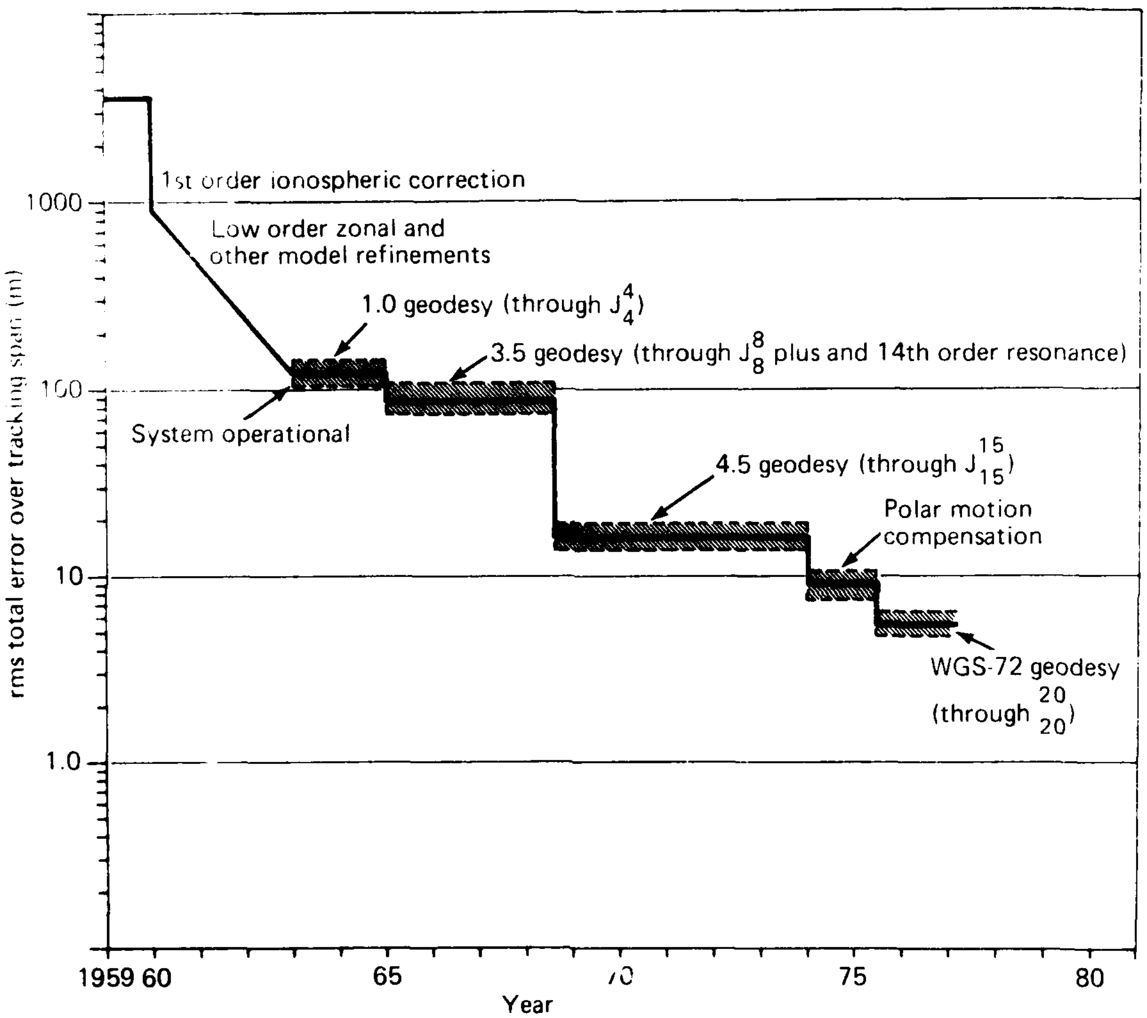

Fig. 8 Tracking accuracy history of OIP.

Table 2

Tracking results for all geopotential models.

			Geopotential Model						
			Set 1.0 Track	Set 2.0 Track	Set 3.0 Track	Set 3.5 Track	Set 4.5 Track	Set PM[1] Track	WGS-72 Track
Days	172	RMSA[2]	0.2588	0.0731	0.0690	0.0619	0.0186	0.0182	0.0137
	173	RMSR[3]	0.1569	0.0557	0.0476	0.0461	0.0150	0.0149	0.0144
Year	1964	RMST[4]	0.3027	0.0919	0.0838	0.0772	0.0239	0.0236	0.0199
			Update	Update	Update	Update	Update	Update	Update
Days	173	RMSA	0.6011	0.3779	0.3787	0.1535	0.0224	0.0219	0.0201
	174	RMSR	0.1686	0.0523	0.0521	0.0485	0.0165	0.0154	0.0097
Year	1964	RMST	0.6243	0.3815	0.3823	0.1608	0.0278	0.0268	0.0222

Note: The results are given in kilometers.

[1]Polar Motion
[2]RMSA - the rms of ECA's (the along-track error)
[3]RMSR - the rms of ECR's (the slant-range error)
[4]RMST - the rms of the total error

$$\left[\frac{1}{N} \sum (ECA^2 + ECR^2)\right]^{1/2}$$

satellites is clearly displaced. As mentioned earlier, satellite 63041 was used for all examples. Not until the geopotential models, APL 4.5 and WGS-72 did we experience any error in the system because of the period of time the experimental data were collected. Since satellite 63041 was launched in 1963, the station and satellite hardware have become outdated and only the satellite oscillator's relative instability contributed to the overall system error significantly as improvements were made in the geodesy models.

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15. V. L. Pisacane, B. B. Holland, and H. D. Black, "Recent (1973) Improvements in the Navy Navigation System," Navigation, Vol. 20, No. 3, Fall 1973, pp. 224-229.

16. B. B. Holland, A. Eisner, S. M. Yionoulis, and H. D. Black, "Implementation of WGS-72 Geopotential Set in the Navy Navigation Satellite System," Developments in Science and Technology, APL/JHU DST-4, 1976, pp. 15-17.

17. T. O. Seppelin, "The Department of Defense World Geodetic System 1972," Can. Surv., Vol. 28, No. 5, Ottawa, Canada, December 1974, pp. 496-586.

18. B. B. Holland, A. Eisner, and S. M. Yionoulis," The Effect of WGS-72 Geopotential in the Navy Navigation Satellite System on Station Surveys," APL/JHU TG 1311, August 1977.

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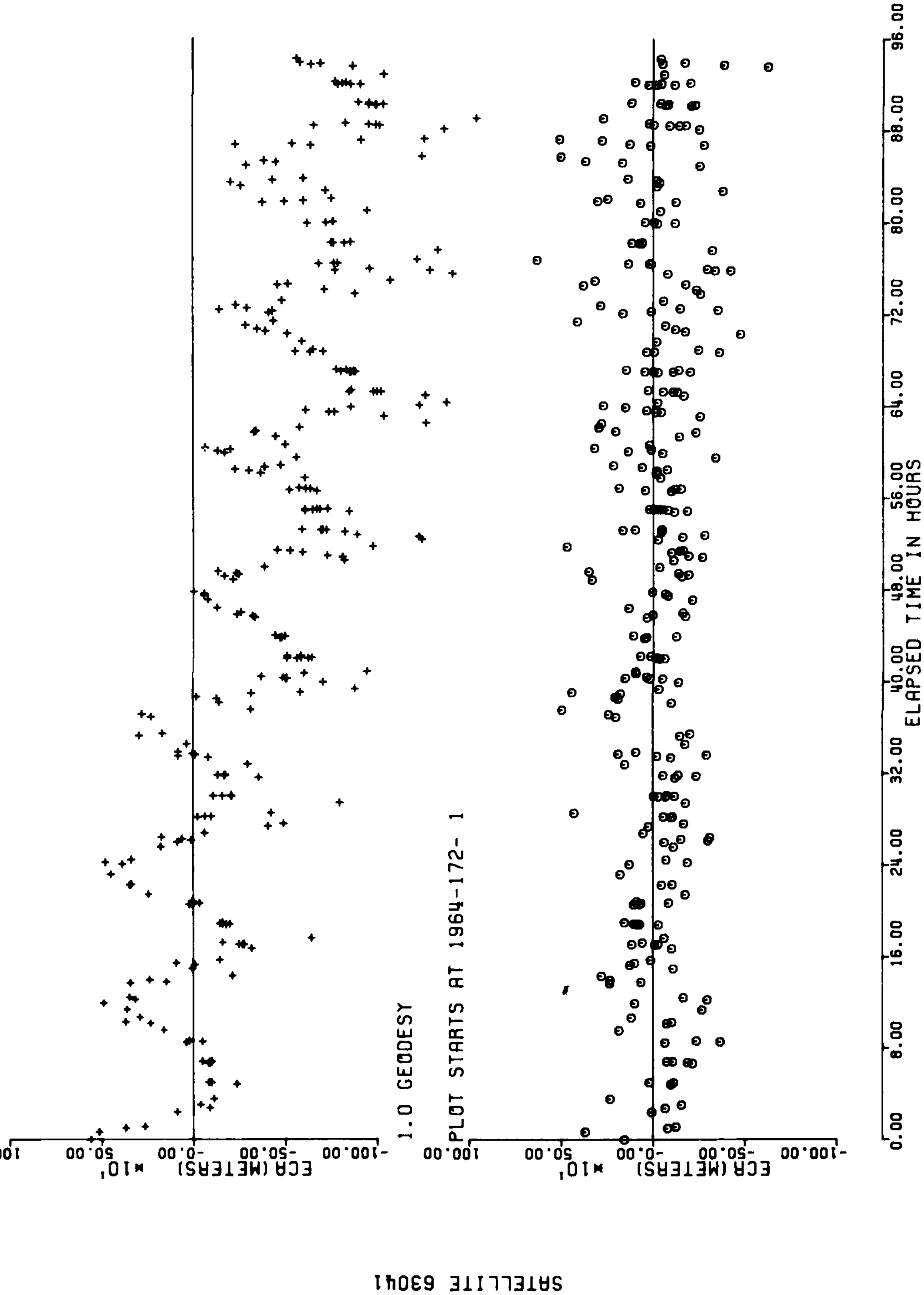
Appendix A
PLOTS



Plot 1

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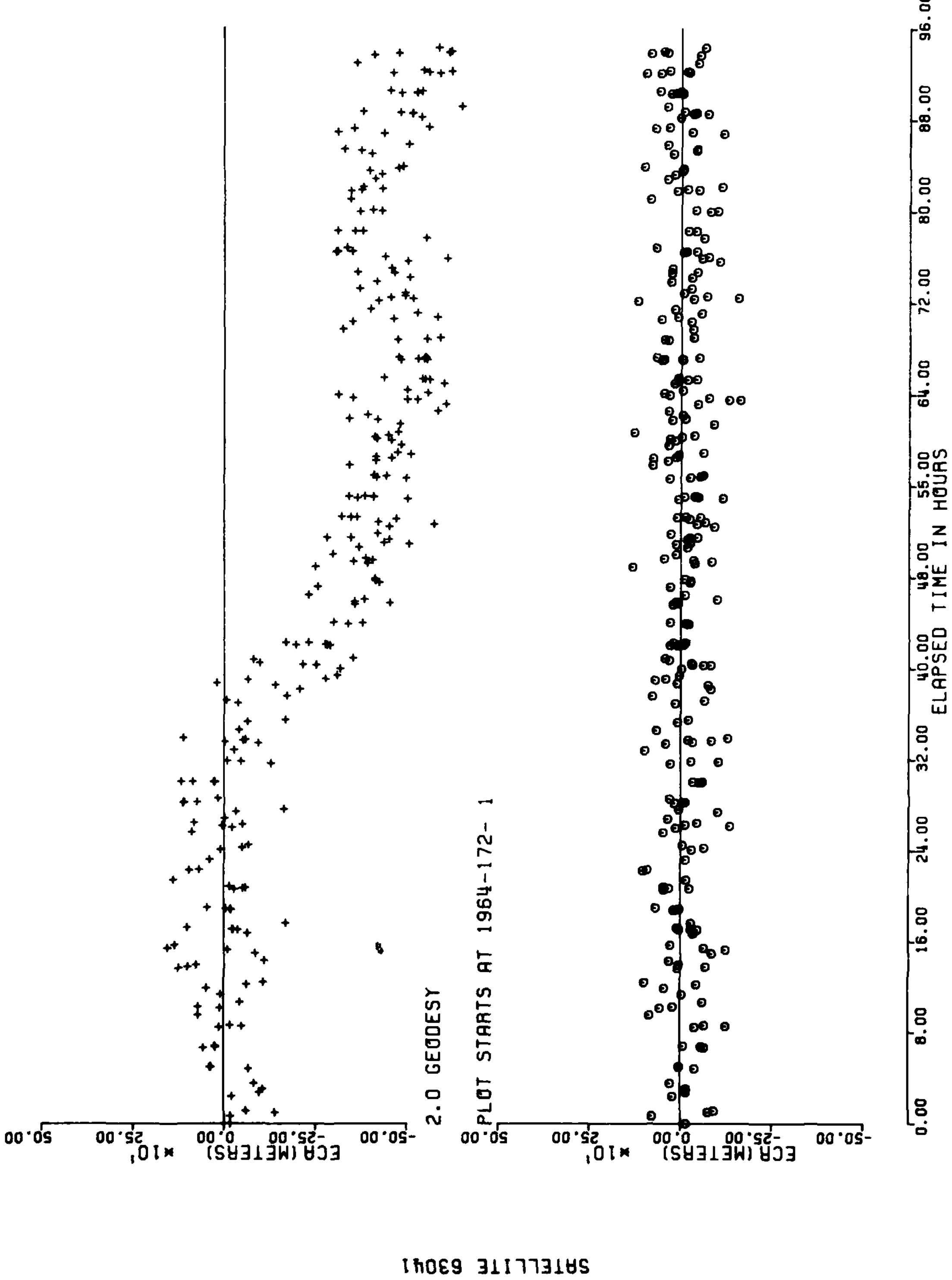
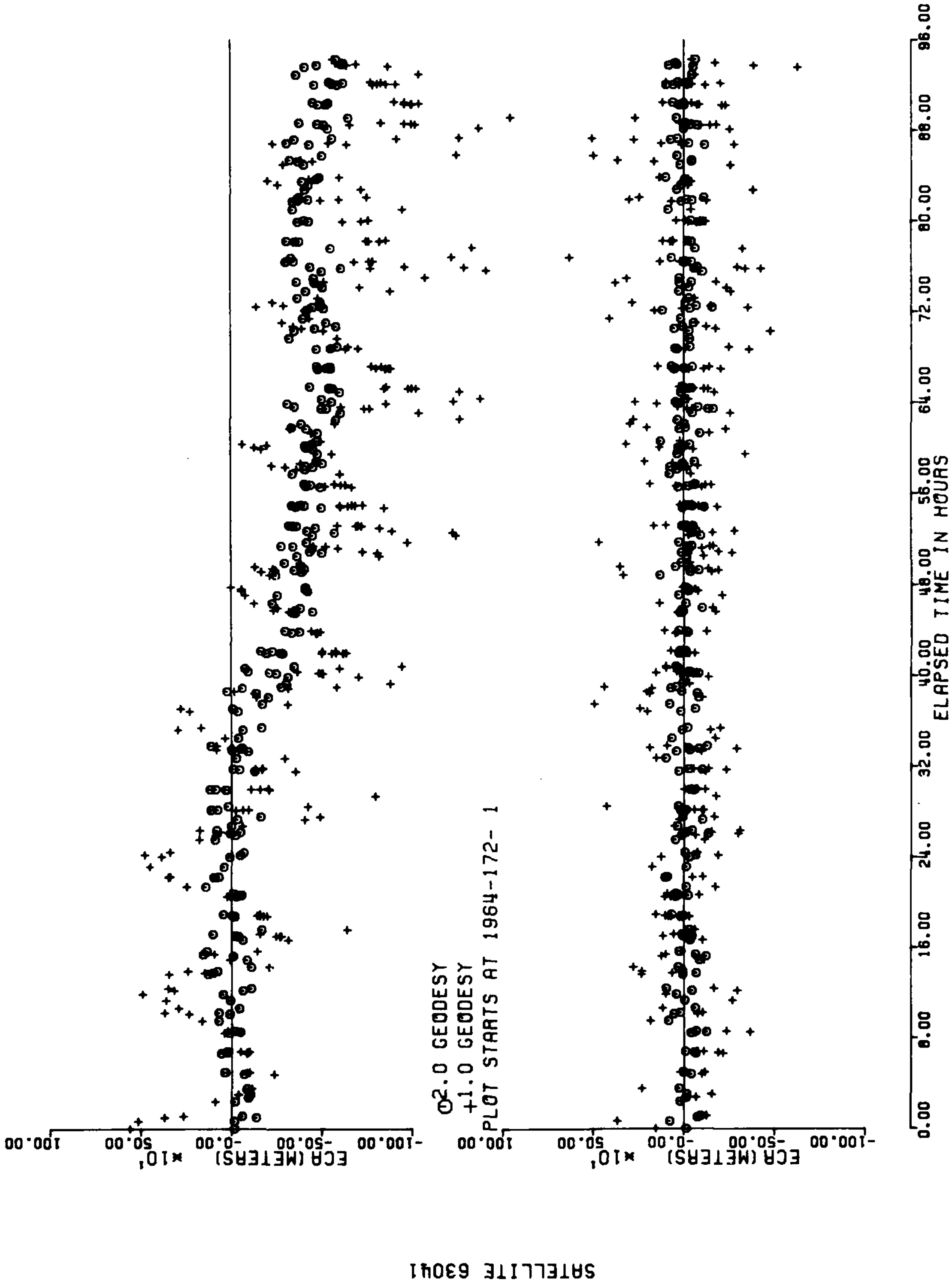

2.0 GEODESY
PLOT STARTS AT 1964-172- 1
ECR(METERS) ×10¹
50.00
25.00
0.00
-25.00
-50.00
ECR(METERS) ×10¹
50.00
25.00
0.00
-25.00
-50.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
88.00
96.00
ELAPSED TIME IN HOURS
SATELLITE 63041

Plot 2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+1.0 GEODESY
PLOT STARTS AT 1964-172- 1
ECR (METERS) ×10¹
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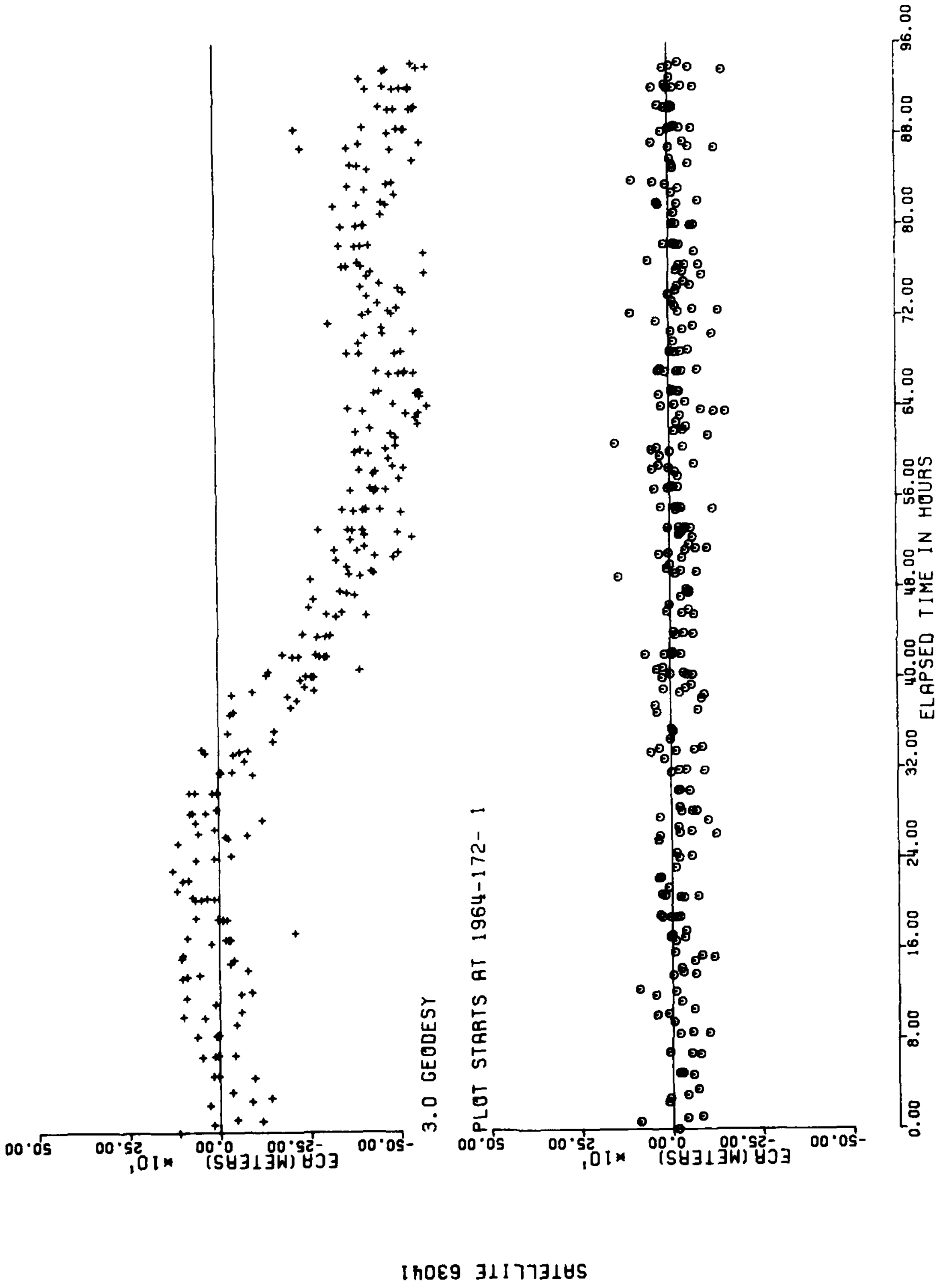
50.00
-0.00
-50.00
-100.00
ELAPSED TIME IN HOURS
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
88.00
96.00
SATELLITE 63041

Plot 3

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
LAUREL MARYLAND



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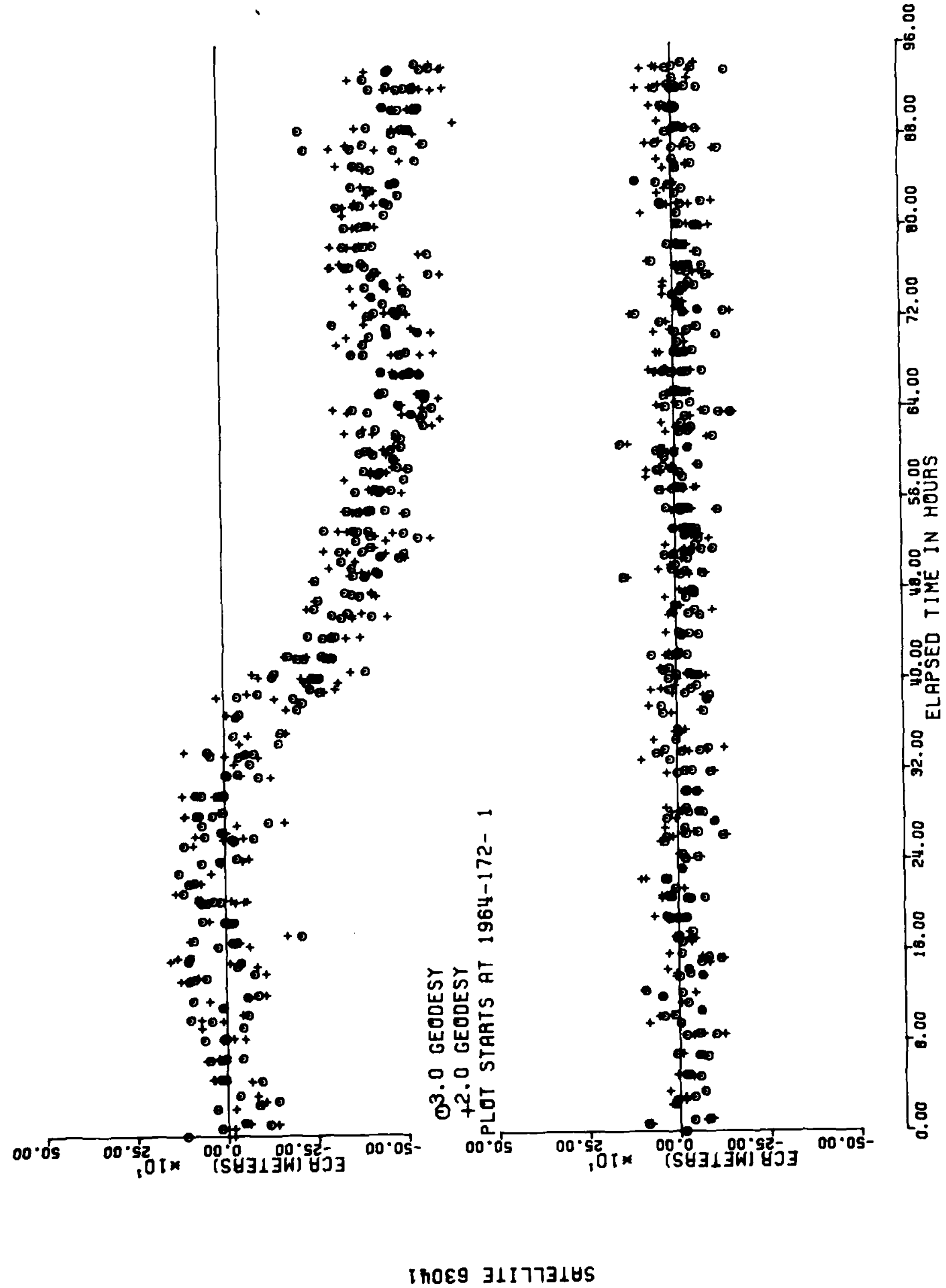
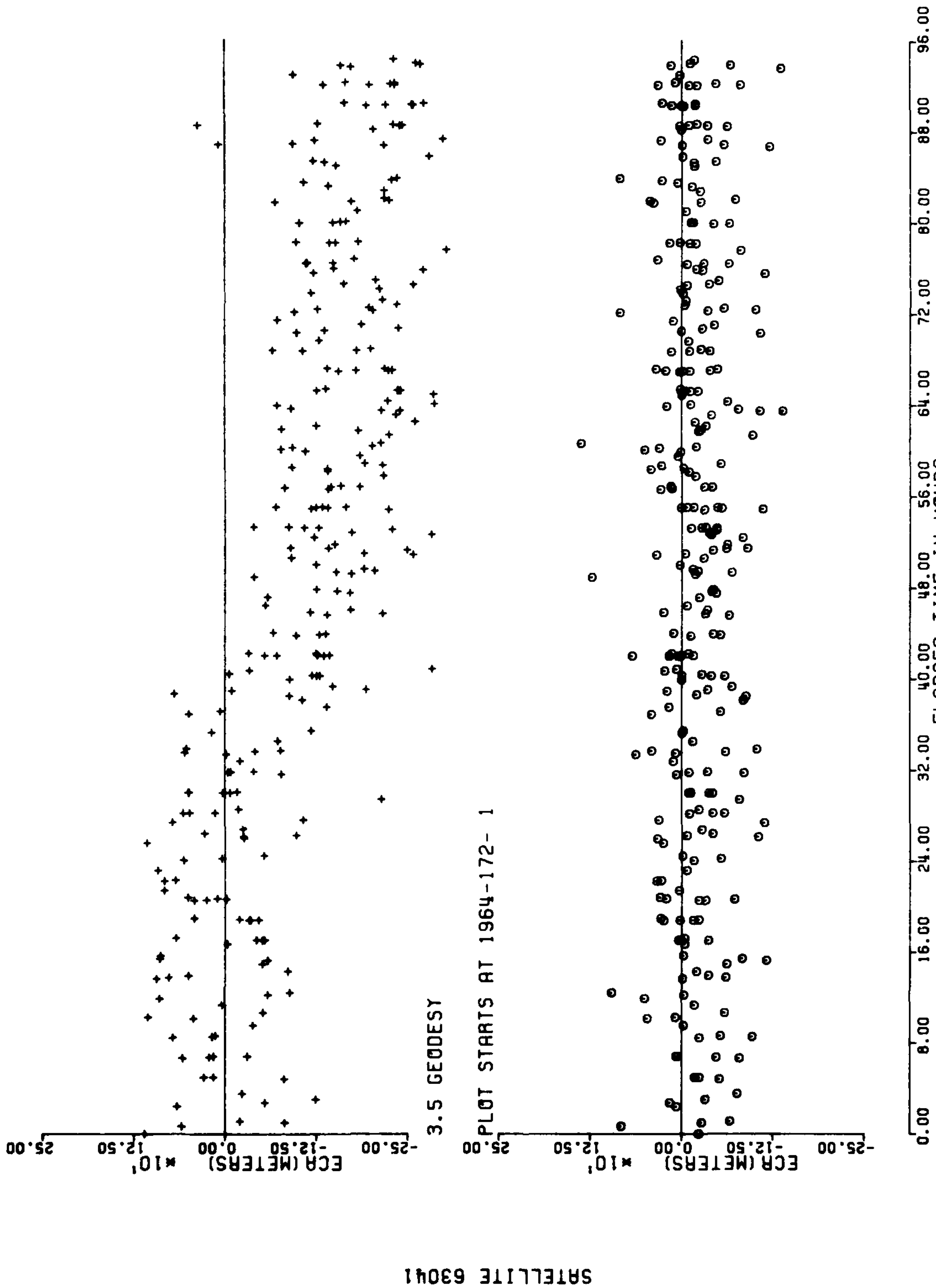

ELAPSED TIME IN HOURS
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
88.00
96.00
ECR(METERS) ×10¹
50.00
25.00
0.00
-25.00
-50.00
⊙3.0 GEODESY
+2.0 GEODESY
PLOT STARTS AT 1964-172- 1
SATELLITE 63041

Plot 5


3.5 GEODESY
PLOT STARTS AT 1964-172- 1
ECR (METERS) ×10¹
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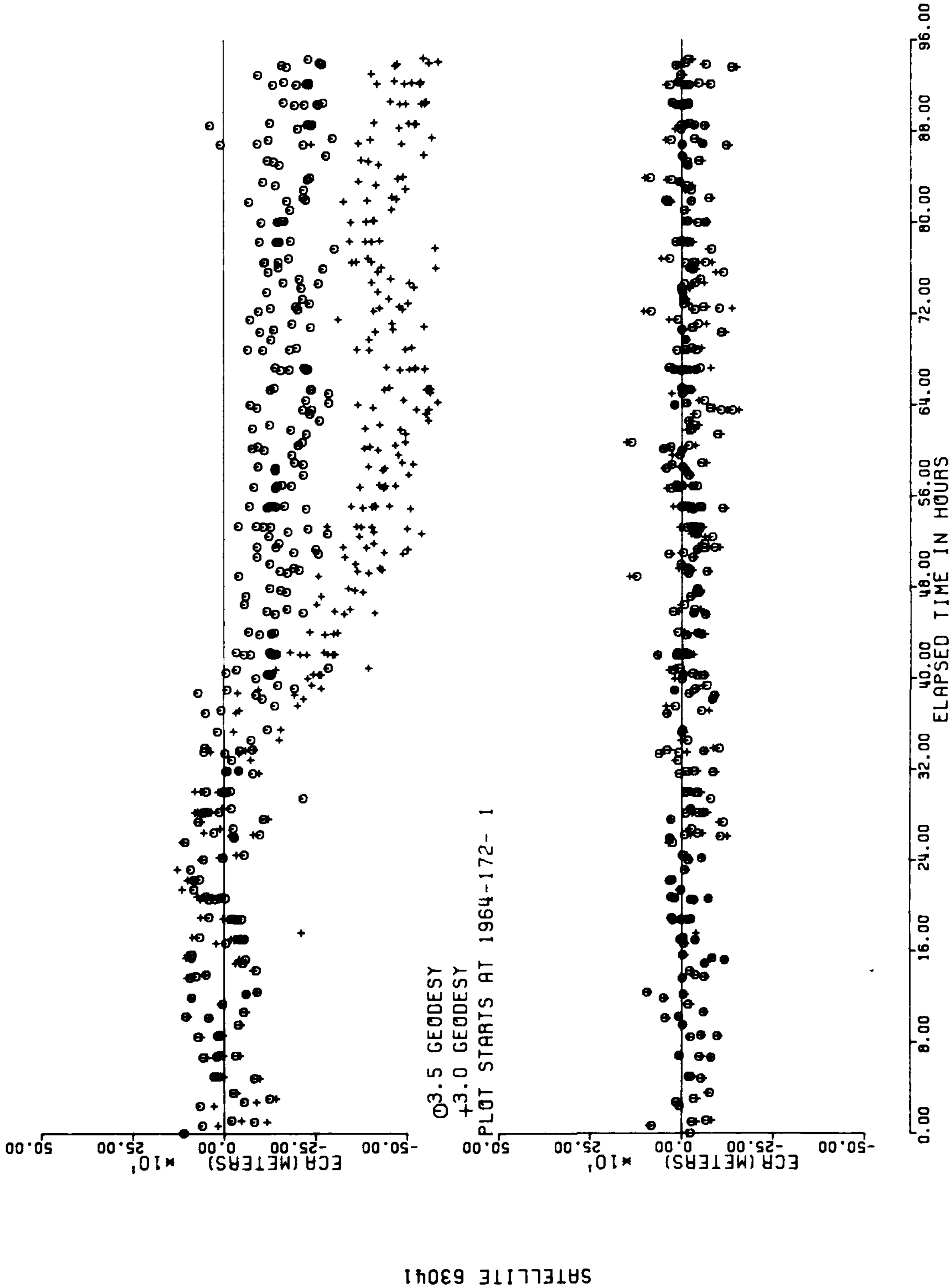
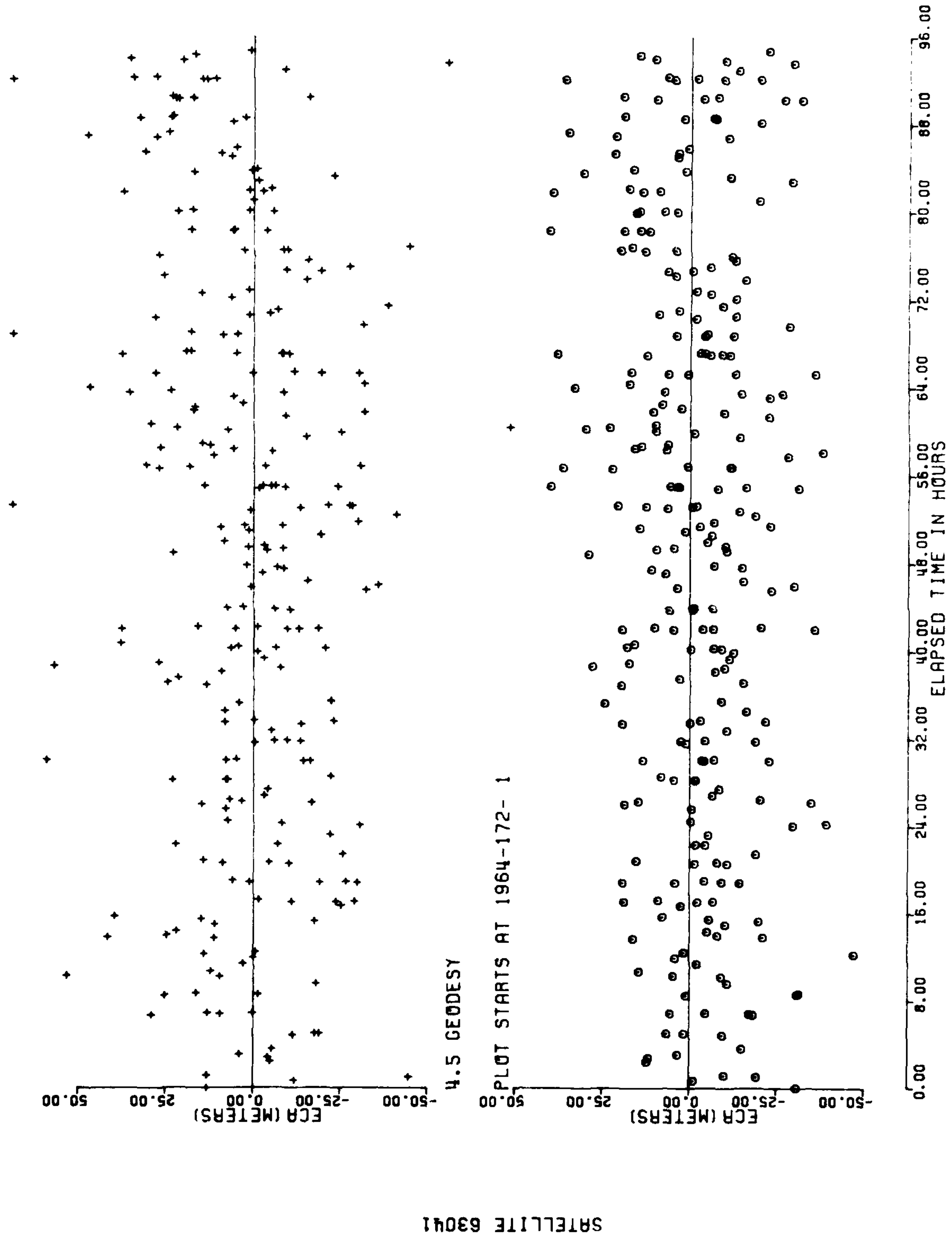
12.50
0.00
-12.50
-25.00
ELAPSED TIME IN HOURS
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
88.00
96.00
SATELLITE 63041

Plot 6

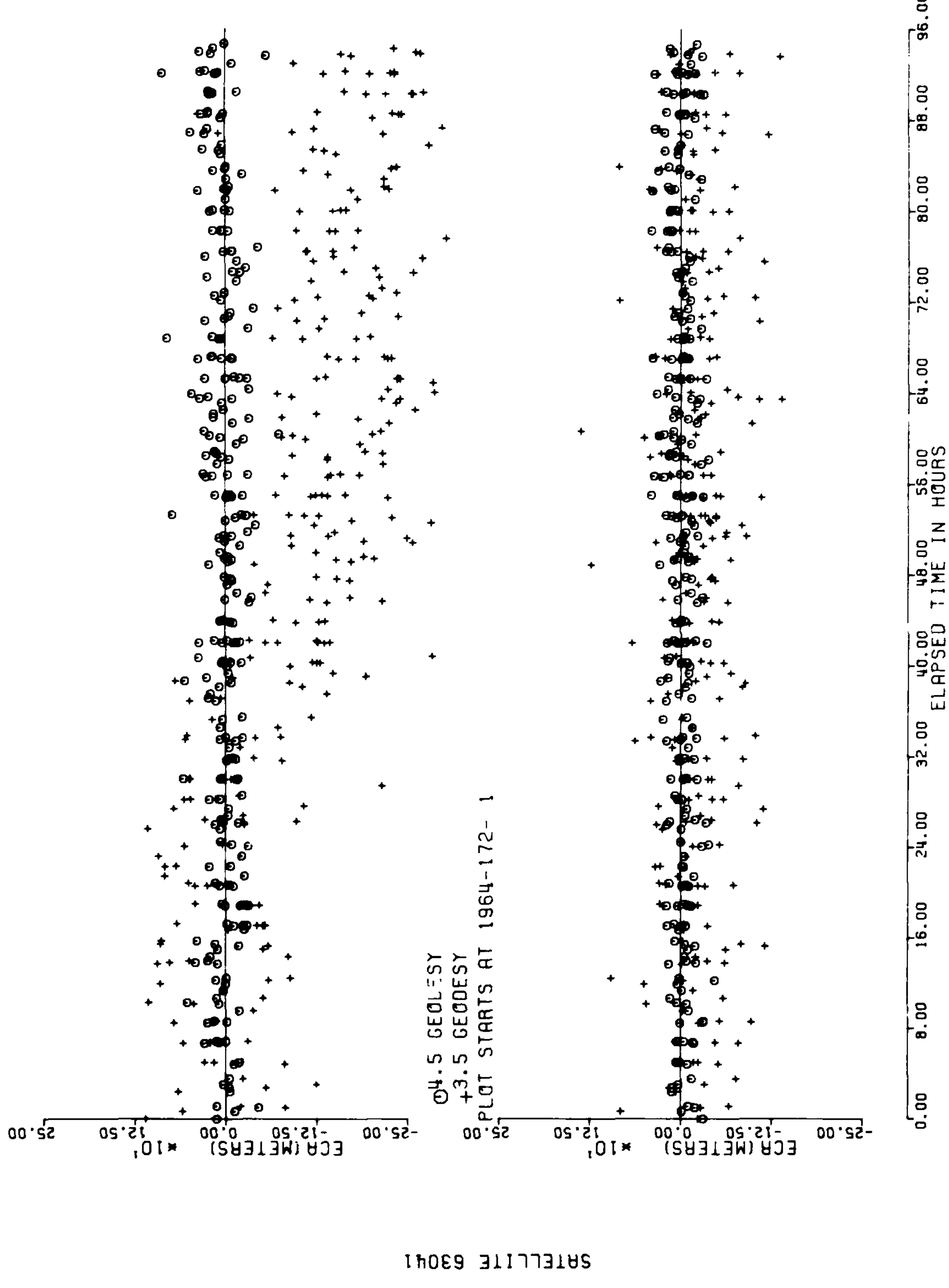

⊙3.5 GEODESY
+3.0 GEODESY
PLOT STARTS AT 1964-172- 1
ECR (METERS) ×10¹
ECR (METERS) ×10¹
ELAPSED TIME IN HOURS
SATELLITE 63041

Plot 7

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
LAUREL, MARYLAND



Plot 8


ECA (METERS) ×10¹
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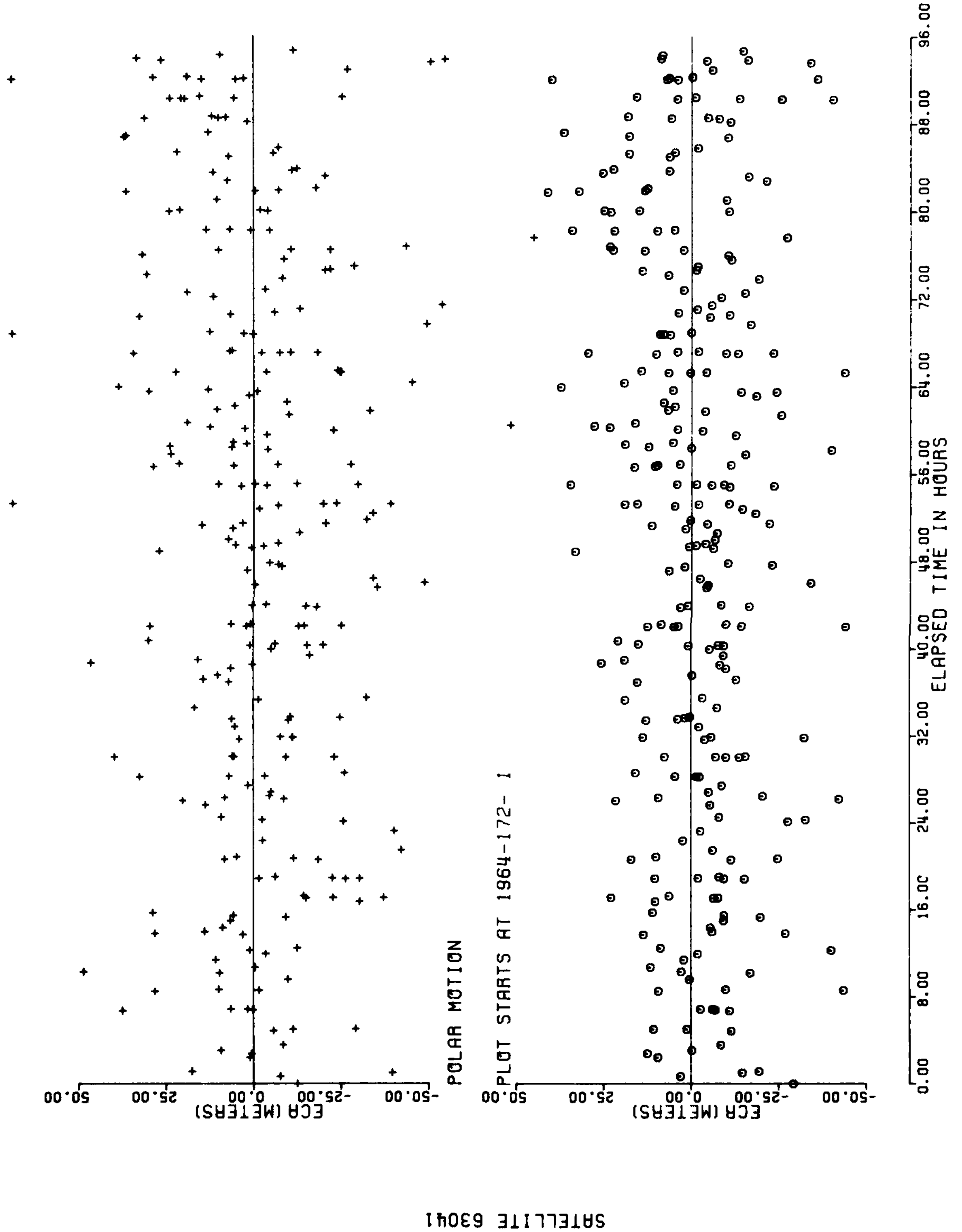
12.50
0.00
-12.50
-25.00
ELAPSED TIME IN HOURS
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
88.00
96.00
⊙4.5 GEODESY
+3.5 GEODESY
PLOT STARTS AT 1964-172- 1
SATELLITE 63041

Plot 9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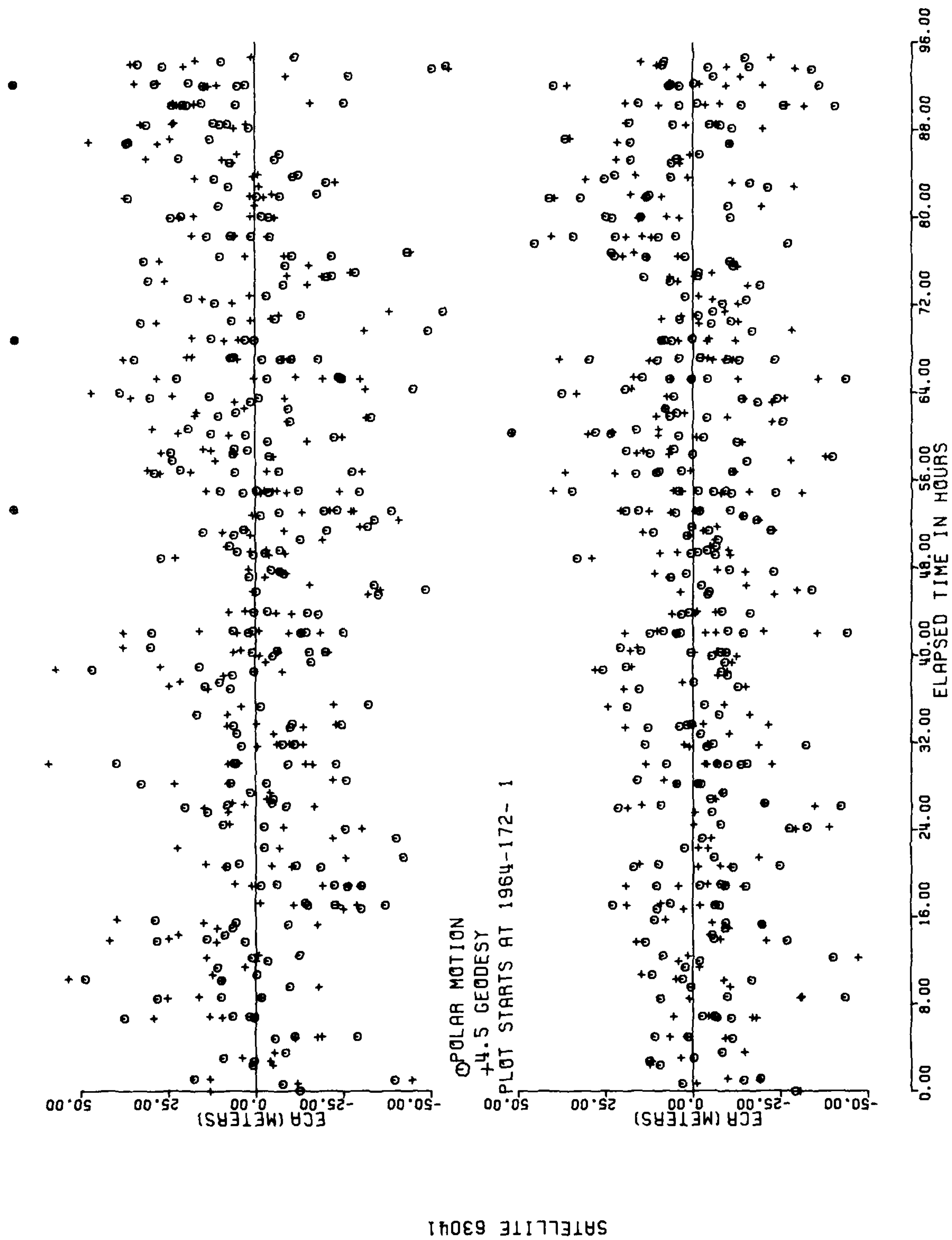
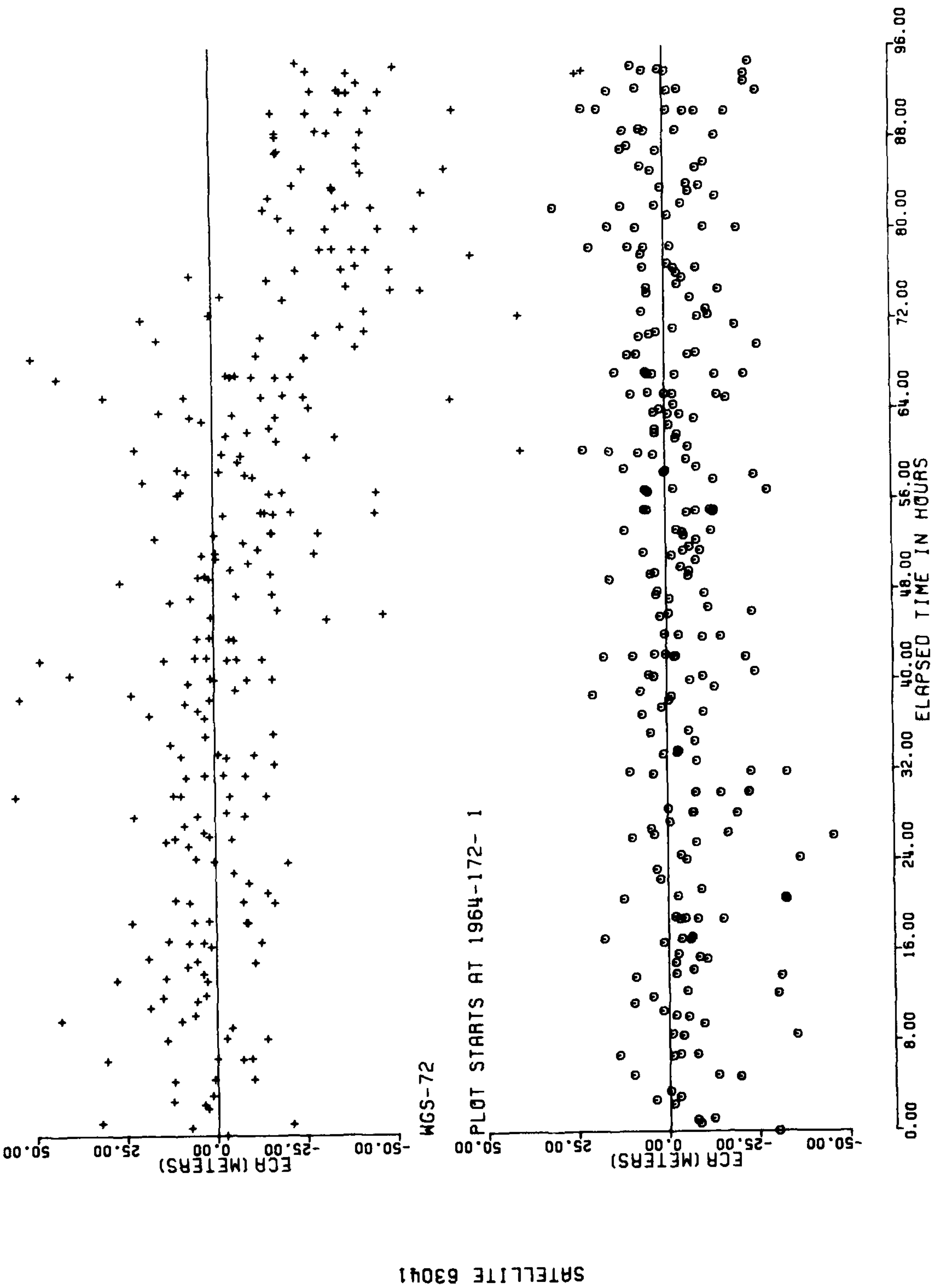
ELAPSED TIME IN HOURS
ECR (METERS)
SATELLITE 63041

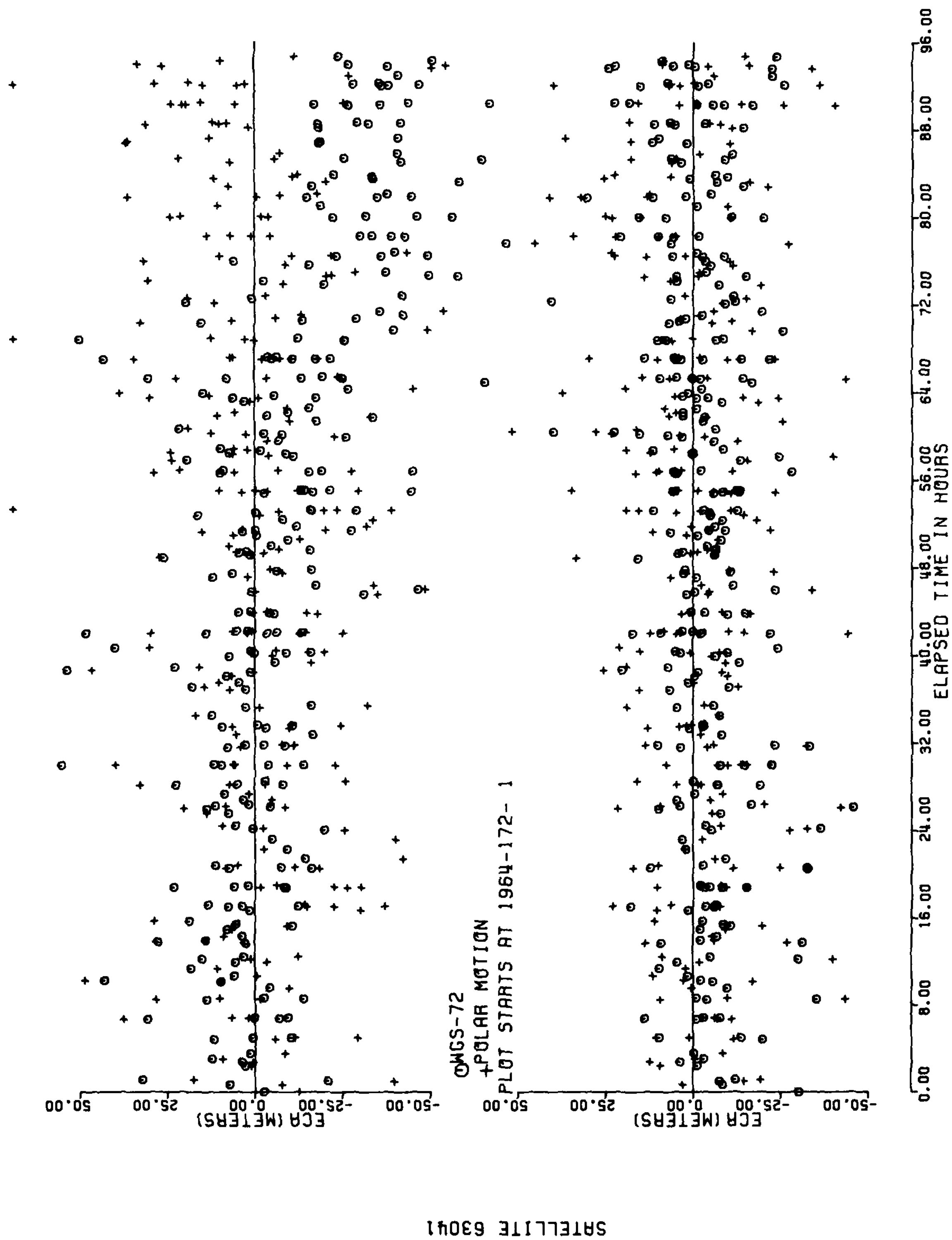
Plot 10


POLAR MOTION
+4.5 GEODESY
PLOT STARTS AT 1964-172- 1
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
88.00
96.00
ELAPSED TIME IN HOURS
50.00
25.00
0.00
-25.00
-50.00
ECR (METERS)
50.00
25.00
0.00
-25.00
-50.00
ECR (METERS)
SATELLITE 63041

Plot 11


WGS-72
PLOT STARTS AT 1964-172- 1
ECR (METERS)
ECR (METERS)
ELAPSED TIME IN HOURS
SATELLITE 63041

Plot 12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25.00
0.00
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-50.00
ECA (METERS)
50.00
25.00
0.00
-25.00
-50.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
88.00
96.00
ELAPSED TIME IN HOURS
O WGS-72
+ POLAR MOTION
PLOT STARTS AT 1964-172- 1
SATELLITE 63041

Plot 13

Appendix B

SECOND GENERATION SYSMITS

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
1.2	S3C	P-2	01/02/64		640938	-4-	FRIDAY THE 13TH DECK.
1.4178	S4C	P-3	06/29/64 07/20/64 04/22/67		660209 641967	-4-	USED FOR PRODUCTION FROM 06/64 to 01/65. FORCES = J44. SET 1.0 GEODESY.
1.4G	S4C	P-3	07/08/64	641607-1	642011	-4-	GEOTRACK SYSMIT.
1.4288	N4C	N-4	10/15/64	642181-1 642120		-4-	MK2MD0. RELEASED.
1.4288	N4C	N-4	04/29/67		670250	-4-	THIS IS MK2 SYSMIT. MK2MD1 MADE IN 01/16/65. FORCES = J66. SET 2.0 GEODESY.
2.0086	2.0	4-E	03/27/65	650094-1	652288	-4-	GEODESY SYSMIT FOR NEWTON'S DRAG TRACKING.
2.0091	2.0	4-E	04/08/65				MK3 PROTOTYPE - NAG.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
2.0130	S4C	4-E	11/05/64	641999-1	641703	-4-	USED FOR PRODUCTION FIRST
			11/15/65		651262		SIX MONTHS OF 1965.
			04/24/67		671041		FORCES = J88, J1313, SET
							3.0 GEODESY.
2.1120	2.0		04/30/65	652098-1	650901		EXPERIMENTAL MK3.
3.0135	3.0	4-E	05/15/65	652311-1	652316	-4-	MK3 PRELIMINARY SYSMIT USED
			05/15/66		651088		FOR PRODUCTION AND SEUSS.
			12/20/65		651657		USED IN 1965 AND 1966.
			12/27/65		651984		FORCES = J1313 AND J1514.
							SET 3.0 GEODESY.
MK3.211	MK3	MK3	07/30/65	651813-1	651719	-4-	FIRST MK3 TAKEN TO NAG.
			09/20/65		650147		BAD INJECT TASK. REPLACED
			09/20/65		650903		WITH MK3.0320. RELEASED.
			09/20/65		651303		
3.0G	3.0	5A1	10/02/65	651077		-3-	GEODESY TRACK - DSR SYSMIT
			08/19/66		652531	-3-	USED FOR GEODESY TO OBTAIN
			07/24/66	662645	661647	-4-	3.5 AND 4.0 GEODESY.
			07/07/66		661609	-4-	USED FOR BOAM EXERCISE.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
3.0320	MK3	MK3	11/22/65	652480-1	652488	-4-	THIS IS MK3MD1 SYSMIT USED
			11/22/65		652370		FORCES TO J1514. USED FOR
			02/10/66		651535		SETS 3.0 AND 3.5 GEODESY;
							USED OPERATIONALLY WITH 3.5
							GEODESY IN 02/66.
3.0HEX	3.0	5A2	12/02/65		651095	-3-	EDITOR SYSMIT FOR HOPFIELDS
							TROPOSPHERE STUDIES.
3.0294	MK3	MK3	10/21/66	661323-1	661077	-4-	MK4 PROTOTYPE SYSMIT HAS
			10/21/66	662015-2	661270		SET 4.4 FORCES AND 4.5
							COORDINATES.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
4.1320	4.1	5A2	11/15/66	661408-1	660474	-4-	HAS 4.5 GEODESY COMPILED.
			11/15/66	660703-2	660259	-4-	HAS NEW DRAG VALUES FROM
			11/17/66		660180	-4-	MEMO S1A-207-66. USED FOR
			01/11/67		660780	-3-	PRODUCTION AND TO OBTAIN
			01/17/67		662611	-3-	5.0 GEODESY. USED AT NAG
			01/17/67		660165	-3-	12/66 AND 06/67. HAS
			04/24/67		661075	-3-	GEOTRACK AND DSR.
MK4	MK4	MK3	01/04/67		651253	-4-	FIRST MK4 SYSMIT USING MK4
			01/04/67		652271		LIBRARY.
4.IRD0	4.1	5A2	02/01/67		661364	-3-	EXPERIMENTAL DRAG SYSMIT.
4.IDR2	4.1	5A2	02/11/67		671139	-3-	EXPERIMENTAL SYSMIT TO
			02/11/67		670045		CHECK OUT DRAG. HAS NEW DRAG
							VALUES. ADDED ALPD AS INPUT.
4.IDF1	4.1	5A2	02/18/67		670555	-3-	EXPERIMENTAL SYSMIT WITH
			02/23/67		650614		DRAG TRACKING. HAS ALL NEW
							VALUES FOR SATAMS, AND
							SATAME WITH SATMM ADDED.

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SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK4MD0	MK4	MK3	02/22/67	670497-1	671148	-4-	HAS 4.5 GEODESY WITH NEW
				670644-2	670808	-4-	DRAG VALUES AND ALPD.
							TAKEN TO NAG 02/27/67.
MK4MD1	MK4	MK3	03/25/67		650825	-4-	USED AT NAG FOR PARALLEL
			04/22/67		660073		RUNS AND OP-EVAL FOR 0-13.
					672219		USED AT NAG FOR DRAG
							EXPERIMENT FOR EISNER.
							SIMILAR TO SYSMIT 4.1DR2.
MK4M1A	MK4	MK3	03/21/67	652283	650947	-4-	SAME AS MK4MD1 SYSMIT EX-
							CEPT HAS CONVERTOR CHANGED
							TO ACCEPT 250 PASSES.
MK4M1B	MK4	MK3	04/22/67		662694	-4-	SAME AS MK4MD1 EXCEPT FOR
			04/22/67		670353		CONVERTOR WHICH ACCEPTS 250
			08/08/67	661894			PASSES WITH PRODUCTION
							SLCHAR. INTAKE USES FINAL
							ORBIT. WAS USED AT NAG FOR
							NEWTONS TRACKS FOR KEPLERS.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK4MD2	MK4	MK3	05/15/67		660848	-4-	SAME AS MK4MD1 EXCEPT WITH
			05/15/67		660476		NEW DRAG MODEL. COMPILED
							AT NAG.
MK4MD3	MK4	MK3	08/05/67	662655-1	671623	-4-	HAS 4.5 GEODESY COMPILED
			08/05/67	671921-2	670480	-4-	WITH UPDATE VAN COORDINATES.
			08/10/67	660855-1	672169	-4-	HAS EISNER'S NEW DRAG MODEL
			08/10/67	651969-2		-4-	WITH K-INDEX AS INPUT. SEE
							MEMO S1A-317-67. SENT TO
							NAG 08/67.
MK4MD4	MK4	MK3	07/28/67	671344	661843	-4-	SAME AS MK4MD3 EXCEPT FOR
							DRAG TRACKING.
MK4DF3	4.1	5A6	12/11/67		672313	-3-	HAS 4.5A GEODESY COMPILED.
			12/11/67		661419	-3-	USES SLCHAR OF 10/26/67.
							SPECIAL SYSMIT WITH DRAG
							FITTING FOR EISNER. FITS
							TO CCD AND LOOPS IN EDITOR.
							HAS OVERLAY CAPABILITY.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK4DF4	4.1	5A6	01/12/68	672568	661477	-4-	SAME AS MK4DF3 WITH CORRECTIONS ADDED. HAS BOTH PRINTER AND CALCOMP PLOTS. RUNS IN BLG. 4 ONLY.
			01/17/68	670281	661328	-4-	
			01/16/68		662491	-4-	
4.1GSL	4.1	5A3	05/22/67		662356	-3-	EDITOR SYSMIT FOR G.S.L. FOR TWO-SECOND DATA (02165).
4.1075	4.1	5A6			660093	-3-	SPECIAL SYSMIT FOR TRACKING POGO SATELLITE AND RANGE RATE DATA. POGO 9 SYSMIT.
4.1075	4.1	5A6			672580	-3-	SPECIAL SYSMIT FOR TRACKING POGO SATELLITE. SYSMIT COMPILED BY M. WALKO. POGO 10 SYSMIT.
4.1075	4.1	5A6			661231	-3-	SIMILAR TO POGO SYSMIT 672580. WAS ESPECIALLY MADE FOR R. YUHASZ AND HAS RELATIVISTIC DOPPLER EFFECT COMPILED. (RELTIV) POGO 11 SYSMIT.
					660971		

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK4MD5	MK4	MK3	02/12/68	670701	680779	-4-	SAME AS MK4MD3 EXCEPT FOR
				680211	670789	-4-	CHANGES TO INJECT TASK.
					670888	-4-	TAKEN TO NAG 02/20/68.
MK4MD5	MK4	MK3	03/29/68	670597-1	661164	-4-	NEW MK4MD5 SYSMIT TAKEN TO
				651873-1	680373	-4-	NAG 04/01/68. THE SAME AS
				651263-2	672527	-4-	OLD MK4MD5 EXCEPT FOR 4.5A
				670432-2		-4-	SLCHAR WITH SATELLITE CHARACTERISTICS. SEE MEMO S1A-366-68A. HAS CHANGES FOR INJECT COMPILED. MADE OPERATIONAL WITH 30140-153B, 30120-155A, 30180-157A, AND 30130-1159A. ALL SATELLITES WERE TRACKED WITH MK4 BY 06/07/68.
MK4M5A	MK4	MK3	06/22/68	670761-1	670338	-4-	MK4MD5A EXPERIMENTAL SYSMIT
				681133-2			USED TO CORRECT ENI BUG IN
			07/05/68	670789-1	680204	-4-	EDITOR. SAME AS MK4MD5.
				650506-2	680808		NOT TAKEN TO NAG.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK4MD6	MK4	MK3	12/21/68	680463-1	682780	-4-	MK4MD6 SYSMIT SENT TO NAG
				681520-2	661930		12/31/68 FOR CHECKOUT.
				682605-1	680861		IMPROVED VERSION OF MK4MD5.
				682921-2	681177		CHANGES ALTERED IN THIS
				680194-1			EDITION OF MK4 DESCRIBED
				680028-2			IN MEMO S1A-440-68.
MK4MD6	MK4	MK3	10/29/69	680320-1	682841	-4-	MK4MD6 MAILED TO APL FROM
				681991-2			NAG. HAS TAPE ASSIGNMENT
							CHANGES. NEW MK3 LOADER
							DECK MUST BE USED. MADE
							OPERATIONAL WITH 30120-280,
							30130-281, 30140-283, AND
							30180-284. ALL SATELLITES
							WERE TRACKED BY MK4MD6 BY
							10/11/69.
MK4MD6	MK4	MK3	04/05/69	690501-1	682269	-4-	MK4MD6 SYSMIT TAKEN TO NAG
				651025-2	660840		BY HOLLAND. CHANGES MADE
				693060-1			IN THIS EDITION OF MK4MD6
				694014-2			ARE DESCRIBED IN MEMO S1A-
			09/19/70		D84	-4-	473-69. NAGS COPY OF SYSMIT.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK5	MK4	MK3	01/04/69	682814-1 681832-2	681703	-4-	MK5 SYSMIT, NOT CHECKED OUT. USES MK3 SYSTAP.
MK5	MK4	MK4	01/04/69	682814-1 681832-2	680050	-4-	MK5 SYSMIT WHICH USES THE NEW MK4 SYSTAP FROM NAG MODIFIED FOR APL BY M. WALKO. INCLUDES ONLY THE TASKS UP TO INTAKE AND PPP. USES 4.5 GEODESY. IF RECOMPILED, SHOULD USE CORRECT STAFSD IN SLCHAR.
MK5MD1	MK4	MK3	12/15/69	671732-1 680343-2 681000-1 680632-2	680406 670342	-4-	SAME AS MK4MD6 EXCEPT FOR 5.0 GEODESY AND COORDINATES. CHANGES DESCRIBED IN MEMO S1A-585-69.
MK5MD1	MK4	MK3	03/11/70	696115-1 696119-2	695096 696095	-4-	SAME AS ABOVE WITH STATION COORDINATE ERROR CORRECTED. USES NEW MK3 LOADER DECK.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK4SAC	MK4	MK3	07/16/70	696134	696289	-4-	USES MK4MD6 AS BASE DECK. CHANGED TO ACCEPT FORCES TO J22 FOR YIONOULIS. HAS SAC FORCES AND COORDINATES.
MK4NWL	MK4	MK3	09/01/70	696065	706593	-4-	USES MK4MD6 AS BASE DECK. CHANGED TO ACCEPT FORCES TO J22 FOR YIONOULIS. HAS NWL-9B FORCES PLUS COORDINATES.
MK4DSI	MK4	MK3	09/28/70	696329	695177	-4-	USES MK4MD6 AS BASE DECK. NEW SPECIAL DRAG TRACKING SYSMIT FOR DISCOS. COMPILED BY HOLLAND AND HOOK.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK4MD7	MK4	MK3	09/07/71	H29-1 H17-2	K83	-4-	NEW MK4MD7 OPERATIONAL SYSMIT. SAME AS MK4MD6 SYSMIT EXCEPT FOR CHANGES BY NAG FOR INJECT. MAKES COORDINATE CHANGE FOR NEW INJECTION STATION AND INCLUDES 502 IN INJECT.
MK4MD7	MK4	MK3	10/04/71	A39-1 A15-2	R82 707270	-4-	NEW MK4MD7 SYSMIT. HAS STATION 502 OFF IN INJECT.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK4 72.049	MK4	MK3	03/02/72	671222-1 707182-2	707196 707128*	-4- -4-	USES MK4MD7 AS BASE DECK. COMPILED WITH POLAR MOTION AND NEW CONVERTOR TO ACCEPT TRANET -CCI- DATA. TAKEN TO NAG 03/09/72 BY HOLLAND. USES INTERMEDIATE P.M. COORDINATES. * THIS SYSMIT HAS UP TO PPP ONLY.
MK4 72.122	MK4	MK3	05/01/72	671656-1 682018-2	707213	-4-	UPDATED AND IMPROVED VERSION OF SYSMIT 72.049.
MK4 73.024	MK4	MK3	02/13/73	706887-1 706623-2	707899 707689	-4-	USES MK4MD7 AS BASE DECK. SIMILAR TO SYSMIT 72.049 WITH NEW POLAR MOTION CO-ORDINATES. INCLUDES DRAG TRACKING. TAKEN TO NAG 02/15/73 BY EISNER AND HOLLAND.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK4 73.065	MK4	MK3	03/26/73	707829-1 696189-2	707956 707659 708310 708080 708310 708209 707938	-4-	SAME AS SYSMIT 73.024 WITH CORRECTIONS TO INTAKE AND INJECT FOR THREE CLUSTERS. TAKEN TO NAG BY PRYOR AND DILLON 03/28/73. POLAR MOTION SYSMIT. HAS P.M. COORDINATES AND 4.5 GEODSEY. MADE OPERATIONAL 01/74. 30120-017, 30190-019, 30140-022, 30180-023, 30130-023, AND 30200-024-74.
MK5MD1 73.155	MK5	MK3	06/06/73		708024	-4-	CHECK OUT SYSMIT FOR GEODESY FOR YIONOULIS AND EISNER. HAS ENLARGED COEFFICIENT TABLES AND USES NEW MK5 LIBRARY. SIMILAR TO SYSMIT 73.065.

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SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK4 74.165	MK5	MK3	06/27/74	708356-1	708734	-4-	PROTOTYPE SYSMIT WITH NEW RADIATION PRESSURE. ALSO HAS SUN AND MOON BODY TIDES COMPILED.
MK4 74.170	MK5	MK3	06/17/74	708885-1	708736	-4-	PROTOTYPE SYSMIT. INCLUDES DRAG FITTING, EDITOR LOOP-ING, AND NEW EAR. SEE MEMO S1A-57-74.
MK4 74.221	MK5	MK3	08/09/74	708814-1	708683	-4-	PROTOTYPE SYSMIT WITH NEW FORCE PACKAGE AND NEW EARTH GRAVITY FORCES. REDUCED RUNNING TIME BY 50%. RE-DUCED TRACKING ITERATIONS FROM FIVE TO TWO.
MK4 74.274	MK5	MK3	10/24/74		709154	-4-	PROTOTYPE WITH WGS-72 FORCES AND P.M. COORDINATES.
MK5MD2 74.319	MK5	MK3	12/06/74		708989	-4-	FIRST PROTOTYPE OF MK5.

SECOND GENERATION SYSMITS

MODEL	LBR.	SYS.	DATE	SYSPIT	SYSMIT	BLG	DESCRIPTION
MK5MD2 74.351	MK5	MK3	12/17/74	707617-1 708275-2	710000 709000	-4-	FIRST MK5MD2 SYSMIT TAKEN TO NAG. HAS ALL THE IMPROVEMENTS FROM EARLIER PROTOTYPES.
MK5MD2 75.129	MK5	MK3	05/10/75		708999	-4-	MK5MD2 PROTOTYPE NO. 2. COORDINATE CORRECTIONS AND NEW KK.
MK5MD2 75.162	MK5	MK3	09/17/75	708631-1 709484-2	709007 709922 707997	-4-	OPERATIONAL MK5MD2 SYSMIT HAS WGS-72 FORCES AND NWL-10D COORDINATES. GRAVITY CONSTANT CHANGED FROM 398601.5 TO 398600.8. OPERATIONAL FROM 12/07/75 TO 12/12/75. ONCE-A-DAY UPDATES WERE INITIATED WITH THIS SYSMIT.

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